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CHARACTERIZATION OF BOTTOM SEDIMENTS AND SELECTED NITROGEN AND PHOSPHORUS SOURCES IN LAKE APOPKA, FLORIDA

Robert F. Schneider, et al

Federal Water Pollution Control Administration
Athens, Georgia

March 1969

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CHARACTERIZATION OF BOTTOM SEDIMENTS AND SELECTED NITROGEN AND PHOSPHORUS SOURCES IN LAKE APOPKA, FLORIDA

by

Robert F. Schneider and John A. Little

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Southeast Water Laboratory
Technical Programs
Athens, Georgia

March 1969

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FOREWARD

Originally this report was intended for limited distribution to the Governor of Florida and to agencies and individuals directly involved in the restoration of Lake Apopka. It provides information requested of the FWPCA on certain characteristics of the lake and its tributary waters. The report is not intended to offer a broad discussion of remedial measures needed to reverse or decelerate the eutrophication of Lake Apopka. A committee is currently considering such measures and is using data available in this report and from other studies to make their decisions.

The report is now being made available to a larger group of scientists and engineers because of its contribution to a body of data reflecting the causes and characteristics of increasingly important eutrophication problems. Through a detailed evaluation of all data which has or is being collected on the process of eutrophication, it is hoped that cures to the ills of excessive nutrient enrichment in all water bodies can be forthcoming.

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CHARACTERIZATION OF BOTTOM SEDIMENTS AND SELECTED NITROGEN AND PHOSPHORUS SOURCES IN LAKE APOPKA, FLORIDA

INTRODUCTION

In recent years one of the most studied lakes in peninsular Florida has been Lake Apopka. Once a nationally known recreational lake where record bass were caught, it has become excessively eutrophic and heavily overpopulated with trash fish. Perpetual algal blooms and extensive unconsolidated bottom deposits covering suitable fish spawning and feeding grounds have added to its many problems.

AUTHORITY

On November 22, 1967, the Governor of Florida requested the Federal Water Pollution Control Administration (FWPCA) to conduct "...a biological-chemical survey of Lake Apopka...". In reply, FWPCA stated "...we are evaluating all of the data collected during the last several years... . As soon as this review is finished...we will be able to recommend to the chairman of your technical committee what, if any, additional work is required." Copies of this correspondence may be found in Appendix D together with the review of previous data collected.

The data review and field and laboratory investigations reported here were performed under the authority of Section 5(b) of the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.).

PURPOSE AND SCOPE OF STUDY

Review of previous investigations of Lake Apopka indicated that some additional studies of the lake bottom and of certain nutrient sources entering the lake would be needed to describe the lake's problems adequately. To meet this need the FWPCA agreed to undertake: (a) mapping of the depth and extent of unconsolidated muck on the lake bottom,

(b) chemical evaluation of selected core samples to show the nutrient quantity and quality of layered material, and (c) determination of nitrogen and phosphorus content of rainfall, citrus grove drainage, and artesian aquifer inflow. (Sources not previously investigated by other agencies).

The field and laboratory studies were designed to complement data being assembled by the Lake Apopka Technical Committee to be used in development of a lake restoration plan. No attempt is made in this report to draw conclusions as to the feasibility or best method(s) of restoring Lake Apopka. Rather, the report presents the findings of the FWPCA investigations described above, together with a discussion of nitrogen and phosphorus data now available for the lake. The Technical Committee, on which FWPCA has representation, is charged with developing a restoration plan. From the data obtained by FWPCA and other agencies, the committee now has at hand adequate information on which to base decisions to respond to this charge.

The technical terminology used in this report is that which has developed during the the course of investigations on Lake Apopka over the last several years.

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to Mr. Darwin Knochenmus of the U.S. Geological Survey for his assistance in selecting sampling locations; and to Mr. John Lundquist for boat and equipment storage facilities at his marina (Fisherman's Paradise).

HISTORY OF LAKE APOPKA

Lake Apopka, located in Lake and Orange Counties in the central portion of peninsular Florida, lies approximately 15 miles west of the city of Orlando (Figure 1). Geological

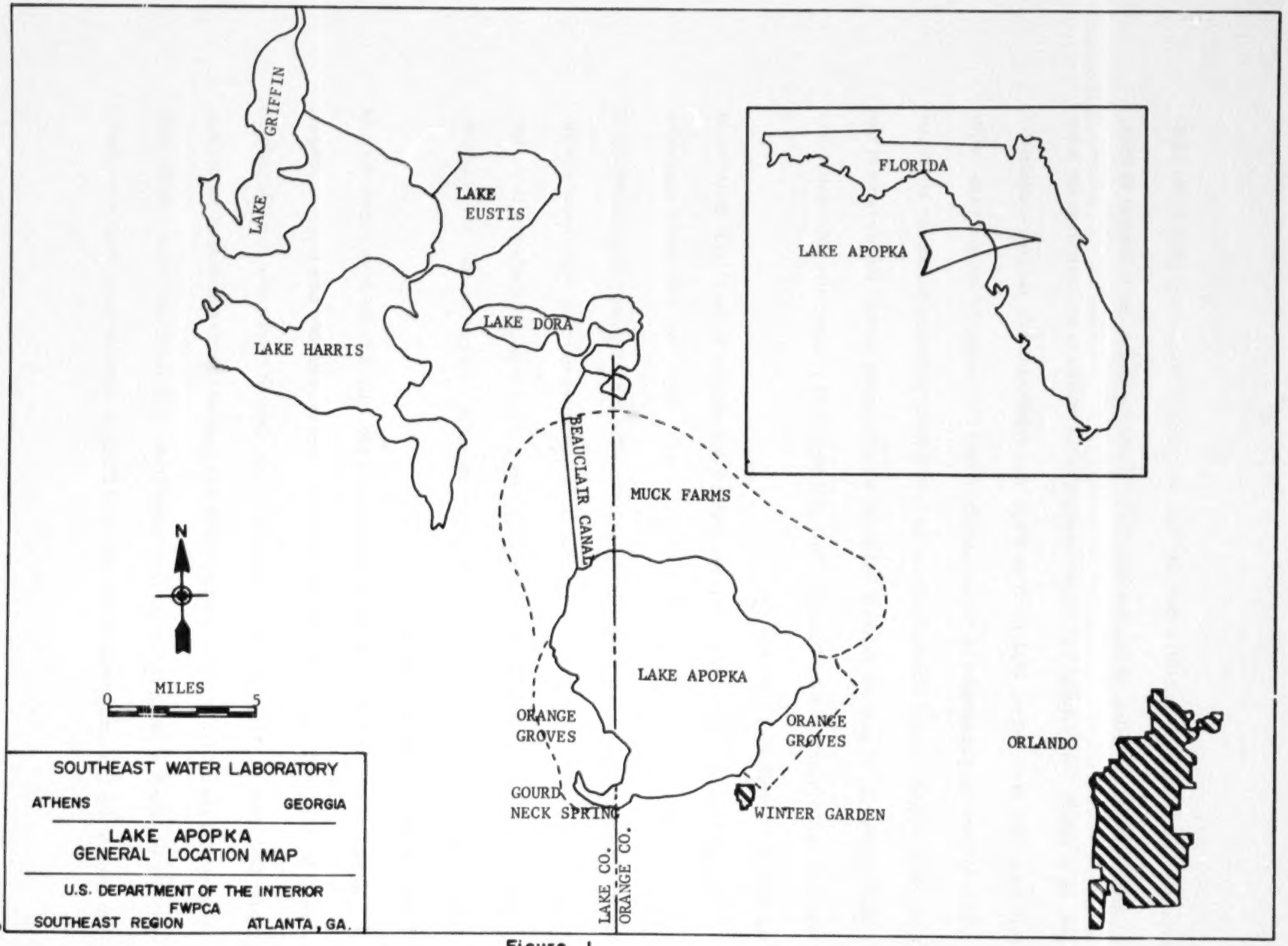
GRIFFIN
LAKE
LAKE
EUSTIS
LAKE HARRIS
LAKE DORA
FLORIDA
LAKE APOPKA
BEAUCLAIR CANAL
MUCK FARMS
N
MILES
0
5
LAKE APOPKA
ORANGE
GROVES
ORANGE
GROVES
GOURD
NECK SPRING
WINTER GARDEN
ORLANDO
LAKE CO.
ORANGE CO.
SOUTHEAST WATER LABORATORY
ATHENS
GEORGIA
LAKE APOPKA
GENERAL LOCATION MAP
U.S. DEPARTMENT OF THE INTERIOR
FWPCA
SOUTHEAST REGION
ATLANTA, GA.

Figure 1.

evidence (MacNeil, 1950) indicates that the lake was formed from a bay prior to the Mid-Wisconsin glacial recession. Extensive deposits of phosphate rock occur in central Florida, and, as a result, a relatively high dissolved phosphorus content is not unusual in the lakes that drain this area (Odum, 1953:1). It is likely that freshwater life became established quickly in Lake Apopka because of the availability of this rich inorganic nutrient base. With time, dead organic matter accumulated on the lake bottom, providing habitat for shoreline rooted vegetation. Vegetative detritus continued to accumulate around the margins of the lake until thick deposits of peat developed. This peat deposition is especially noticeable along the northern shoreline of Lake Apopka.

Recent history of the lake is well documented and detailed in the Florida State Board Reports of 1964 and 1965 (Burgess, 1964; Huffstutler, et.al., 1965). By 1946 littoral vegetation had gained foothold throughout most of the lake bottom. The following year, large quantities of aquatic plants were uprooted by a hurricane. Soon thereafter the first algal bloom was reported. The dense attached aquatic plants (Vallisneria) never became established in the lake again, probably because of a partial black-out effect caused by the algae bloom. The character of the lake was materially changed.

In 1948 Beauclair Canal was opened connecting Lake Apopka to the downstream chain of lakes. In 1952 a control structure was installed in the canal to regulate water levels in Apopka. From that point on, the character of this water body changed from a lake to a mismanaged reservoir. Lake drawdown for fish management was ignored. During periods of excess run-off, the surrounding muck farms pumped water from their fertilized fields into the lake. Municipal waste (presently treated) and untreated citrus processing wastewater were poured

into the lake at the city of Winter Garden. Unknown acreages of water hyacinths were sprayed with herbicides and left to decompose. Algal blooms became persistent, and the lake visually resembled pea soup. Fishermen became irate and began to seek other fishing areas.

The Florida Game and Freshwater Fish Commission survey of 1956 revealed that game (sport) fish were essentially gone, either by migration, death, or failure to spawn. The Commission reported a species composition by weight of 82 percent rough fish (mostly shad) and 18 percent game fish (Heinen, 1959).

The lake was treated with rotenone for gizzard shad and threadfin shad removal in November 1957; August 1958; and September 1959. It was estimated by M.T. Huish, Project Leader for the Commission (personal communication), that 20 million pounds of shad were killed during the three operations. These fish were left to decompose in the lake. As a result of released nutrients bound in the bodies of the shad, an extremely dense phytoplankton bloom followed each treatment.

In May 1963, three million pounds of fish were reported killed in Lake Apopka (Woods, personal communication). A report was released by the Florida State Board of Health in July 1963 concerning this fish kill, indicating the cause to be gas (oxygen or nitrogen) embolism. During the following two years, the Florida State Board of Health conducted a limnological survey and found that dense floating phytoplankton blooms were shading underlying phytoplankton, causing them to die and sink to the lake bottom where they formed unconsolidated deposits of organic material. These flocculent deposits were anaerobic and did not afford a suitable habitat for benthic biota. Hence, forage fish seeking food and spawning grounds were restricted to the remaining productive zone around the lake perimeter. This

condition still exists today. The Florida State Board of Health estimated the feeding and spawning grounds to be less than 2,000 acres in this 30,000-acre lake.

On April 4, 1967, the Governor of Florida appointed a Technical Committee to evaluate restoration of the lake. Sixteen agencies, including the Federal Water Pollution Control Administration, accepted the invitation to become active participants in the project.

In March 1968, the field survey to characterize the lake bottom materials was undertaken by staff from the Southeast Water Laboratory. This report is based on findings from this survey.

SUMMARY

1. Lake Apopka, with a 30,000 acre surface area and an average depth of 6 feet, is a shallow, eutrophic lake located in peninsular Florida, approximately 15 miles west of the city of Orlando. Perpetual algal blooms and extensive deposits of unconsolidated muck have resulted in a poor fishery, reduced recreational use, and irate lakeside land owners.
2. At the request of the Governor of Florida, a review of Lake Apopka's eutrophication problem was made. This review indicated the need for additional field studies. These studies were conducted by FWPCA in March 1968 to: (a) map the depth and extent of unconsolidated muck on the lake bottom, (b) determine certain physical and chemical characteristics of the bottom deposits, and (c) augment existing data on nitrogen and phosphorus sources by showing the relative importance of rainfall, citrus grove drainage, and inflow from the artesian aquifer.
3. Eighty-nine sampling stations were established in the lake and 267 bottom deposit samples for chemical analyses were collected with a piston-type coring device.

4. Water samples for chemical analyses were collected from six artesian wells, three shallow wells, the principal lake spring (Gourd Neck) and two rain gauges.

FINDINGS

1. Unconsolidated bottom sediment (muck) covers 90 percent of the lake bottom. In areas the deposit is 40 feet thick, but it averages 5 feet. Anaerobic conditions and flocculent consistency of the sediment make these areas unsuitable for fish-food organisms and game fish. Deposits of peat[1/] are found along most of the lake shoreline, especially along the northern shore. Although peat deposits are more consolidated than muck, they are similarly anaerobic and provide little or no suitable substrated for desirable biota. Exposed deposits of sand, clay and shell provide the only biologically productive bottom area. These deposits cover an area estimated to be 1650 acres, five percent of this 30,000 acre lake.
2. Chemical analyses revealed that the top three feet of lake sediments contain approximately one half billion pounds total nitrogen and five to ten million pounds of total phosphorus.[2/] With the exception of isolated bottom areas of shell, sand, or clay, distribution of these nutrients is relatively uniform over the lake. Individual values of total nitrogen range from one to four percent (dry weight) in muck deposits, while total phosphorus varies between 0.02 and 0.21 percent. Phosphorus concentrations usually decrease below the top few centimeters of the lake bed.
3. The average COD value for muck samples (dry weight) is 1100 mg/g, while solids content seldom exceeds 5 percent in surficial samples or 12 percent at 3-foot depths. The volatile solids fraction comprises 32 to 77 percent of the total.

[1/] Peat deposits contain visible vegetable tissue and were distinguished from muck on this basis.

[2/] Total nitrogen and phosphorus include inorganic and organic fractions.

3. Analysis of water collected from three shallow "seepage" wells located along the citrus grove area of the shoreline showed a significant nitrogen and phosphorus content. The nitrate-nitrite (as N) concentration ranged from 2.7 to 30.6 mg/1 and phosphate (as P) varied from 1.4 to 52.9 mg/1. Additional information is needed on subsurface flow from citrus groves before the quantities entering the lake can be estimated.

4. Based on an annual precipitation of 50 inches and three rainwater analyses, the estimated nitrogen and phosphorus loading from rainfall directly on the lake is 6 lb/acre/yr total N and 0.7 lb/acre/yr total P. Compared with other sources entering the lake, these amounts of N and P are significant.

5. Groundwater from the Floridian Aquifer feeding Gourd Neck Spring contains relatively low concentrations of nitrogen and phosphorus. Except for one sample (Monteverde Academy artesian well), the artesian aquifer had nutrient values that ranged between 0.10 and 0.16 mg/1 total N and 0.01 to 0.06 mg/1 total P.

6. Any plan for restoration of Lake Apopka must include a program of reducing nutrient (principally nitrogen and phosphorus) input. Removal of nutrients already in the system must be considered as well. Point sources such as agricultural runoff pumped into the lake and municipal and industrial waste appear to be the principal controllable nutrient inputs. Direct rainfall on the lake, recycling of nutrients from the sediments, and possible high input from the citrus grove runoff are also considered important although much less amenable to control. A summary of information on nitrogen and phosphorus sources and sinks indicates that substantial data are now available on which to base restoration measures.

STUDY METHODS

FIELD STUDIES

Lake sediment samples and samples from certain nutrient sources were obtained during the March 1968 survey. Eighty-nine sediment sampling stations were established for the lake (Figure 2, see foldout in back of report). Most stations were selected by applying a two-inch grid pattern over a composite map made up from the Clermont East, Winter Garden, Apopka, and Astatula, Florida, U.S. Geological Survey quadrangle maps (scale of one-inch equals 2,000 feet). The distance between stations was 4,000 feet with the two-inch grid.

The small size of the Gourd Neck spring area allowed only three stations to fall into this important section by using the two-inch grid. To obtain more data for this area, a one-inch grid was used and ten stations were established in Gourd Neck at intervals of 2,000 feet.

Stations were located on the lake by sighting on known landmarks with a bearing scope, or, where shoreline clearing permitted, a transit was used to sight along transect lines. Each station was marked by an anchored one cubic foot styrofoam buoy with flag. Additional buoys were anchored approximately 500 feet apart in a line between stations to aid the boat driver in keeping on a given course. The buoy course was run at 10 mph by a boat equipped with a special speedometer, and a recording fathometer charted water depth and lake bottom contour.

Cores of bottom sediments were obtained from each sampling station with a piston-type coring device. The device collects a relatively undisturbed one-meter core, [1/] seven centimeters in diameter (Schneider, in press). Physical characteristics of each core were determined in the field. Segments seven centimeters long were taken from the top, middle and bottom of each core to be used in determination of stored nutrients. These samples were

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[1/] The composition of the lake bottom sometimes prevented a full one-meter long core from being collected.

placed in labeled plastic "Whirl-Paks" and packed with dry ice in an insulated styrofoam carton for shipment to the Southeast Water Laboratory in Athens, Georgia.

Water samples for nitrogen and phosphorus determination were collected from four sources: (a) shallow "seepage" wells in citrus grove areas, (b) wells from the Floridian aquifer, (c) Gourd Neck Spring, and (d) two rain gauges (Figure 2). Personnel from the U.S. Geological Survey selected the well sites based on their knowledge of groundwater piezometric levels and permeability of the soils in Lake and Orange Counties. Gourd Neck Spring was selected for sampling because it was the only known flowing spring in the lake. A one liter Kemmerer water sampler was used to collect samples from the spring at a 25-foot depth. Rain gauges were temporarily placed on the shoreline to measure and collect rainwater that fell upon the lake's surface. The gauges were precleaned immediately (with deionized water) prior to each of three sample collections during March 1968. All water samples were acid preserved and frozen in plastic bottles (cubitainers), packed in dry ice, and shipped to the Southeast Water Laboratory, Athens, Georgia, for chemical analysis.

LABORATORY STUDIES

In the laboratory, the water samples from the spring, wells, and rain gauges were analyzed for total Kjeldahl nitrogen, nitrate-nitrite nitrogen, ammonia nitrogen, and total phosphate. These analyses were made with AutoAnalyzer methods used routinely by the Southeast Water Laboratory for nutrients in water. The three shallow "seepage" well water samples contained fine silt and were filtered through an acid-washed 0.45 u membrane filter prior to analysis. [1/]

Sediment samples were analyzed for total Kjeldahl nitrogen, nitrate-nitrite, nitrogen, chemical oxygen demand, total phosphate, and total and volatile solids. Generally, analytical

---

[1/] Since samples were not prefiltered prior to acidification, this procedure is not a means of separating soluble and insoluble fractions.

procedures followed the methods described in the Great Lakes Region Chemistry Laboratory Manual for Bottom Sediments (Federal Water Pollution Control Administration, 1968). A brief description of the laboratory procedures for sediments may be found in the Appendix.

RESULTS

WATER DEPTH

Fathometer data was used to construct the water depth map presented in Figure 3. Charts from the recording fathometer showed that Lake Apopka had an average water depth of about six feet. With the exception of the flowing spring at Gourd Neck, the maximum water depth was found in two shoreline trenches. Each of these trenches was located within 150 feet of the shoreline and each paralleled the shoreline for several miles. The first and deepest trench (maximum depth of 18 feet) was found adjacent to the southern shoreline. It began west of the Winter Garden Municipal Pier and continued into Gourd Neck to the flowing spring. The second trench followed the western shoreline. It began adjacent to the City of Monteverde water tower and followed the shoreline in a southerly direction to the mouth of Gourd Neck.

PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF BOTTOM DEPOSITS

The characteristics of the muds on the bottom of Lake Apopka have been responsible for many of the lake's problems. For the most part, the deposits found were unconsolidated.

Data from fathometer charts, coring, probing, Corps of Engineers' studies, and the Orange County Engineering Department were used in drawing a contour map of the unconsolidated sediment thickness (Figure 4).

Surficial sediments consisted of approximately 99 percent water; and the ooze beneath, at a one-meter depth, was slightly more dense (90 percent water). These soft deposits covered more than 90 percent of the bottom. In some areas the unconsolidated deposition was at least 40 feet thick; average thickness throughout the lake was approximately 5 feet. The physical composition of cored material for each sampling station is shown in Appendix B.

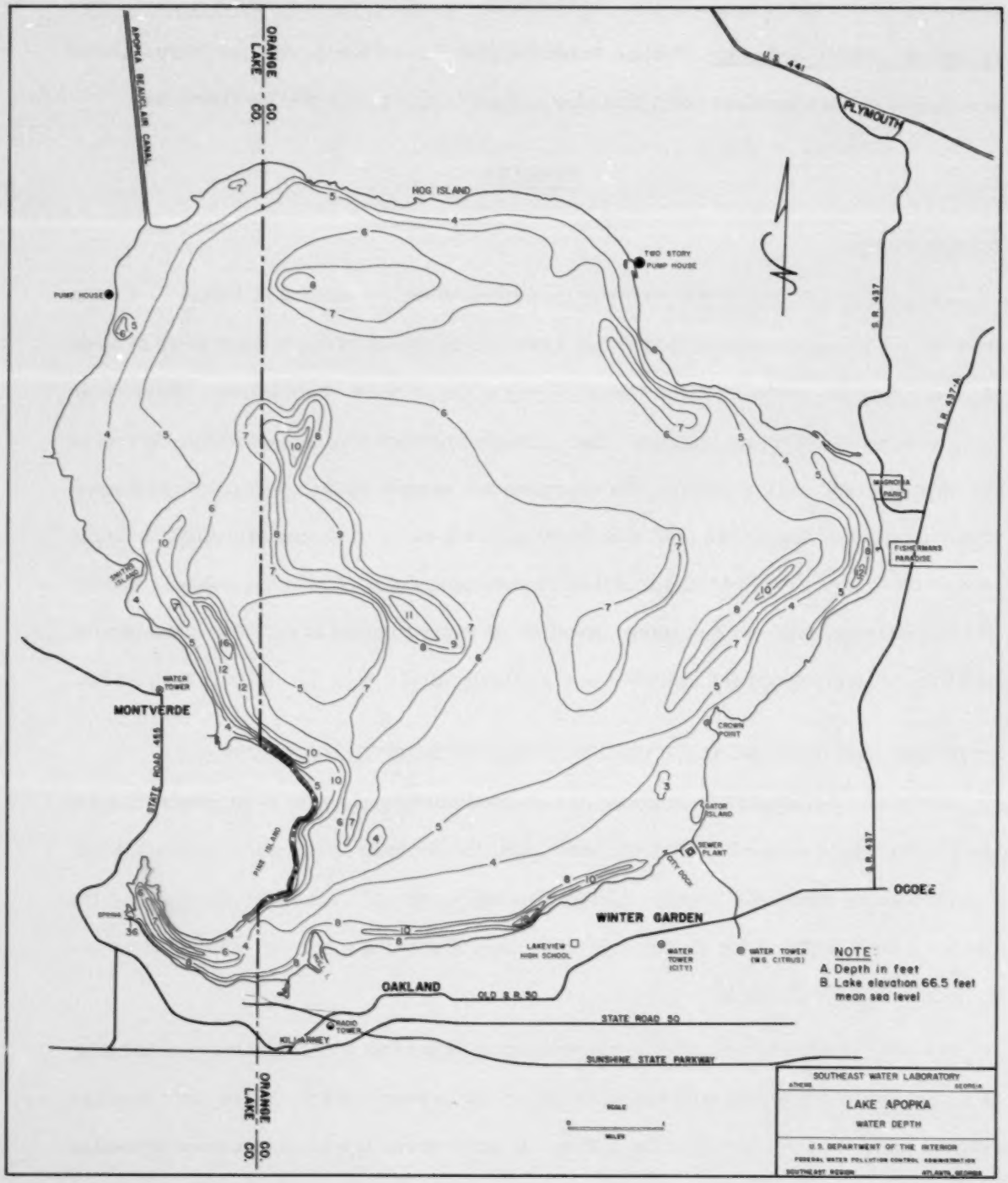

APOPKA BEAUCLAIR CANAL
ORANGE CO.
LAKE CO.
HOG ISLAND
TWO STORY PUMP HOUSE
PUMP HOUSE
U.S. 441
PLYMOUTH
S.R. 437
S.R. 437-A
MAGNOLIA PARK
FISHERMANS PARADISE
SNAKE ISLAND
WATER TOWER
MONTVERDE
STATE ROAD 455
PINE ISLAND
CROWN POINT
GATOR ISLAND
SEWER PLANT
CITY DOCK
OCOEE
WINTER GARDEN
LAKEVIEW HIGH SCHOOL
WATER TOWER (CITY)
WATER TOWER (W.G. CITRUS)
OAKLAND
OLD S.R. 50
STATE ROAD 50
RADIO TOWER
KILLARNEY
SUNSHINE STATE PARKWAY
NOTE
A. Depth in feet
B. Lake elevation 66.5 feet mean sea level
SOUTHEAST WATER LABORATORY
ATHENS GEORGIA
LAKE APOPKA
WATER DEPTH
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHEAST REGION ATLANTA, GEORGIA
SCALE
MILES

Figure 3

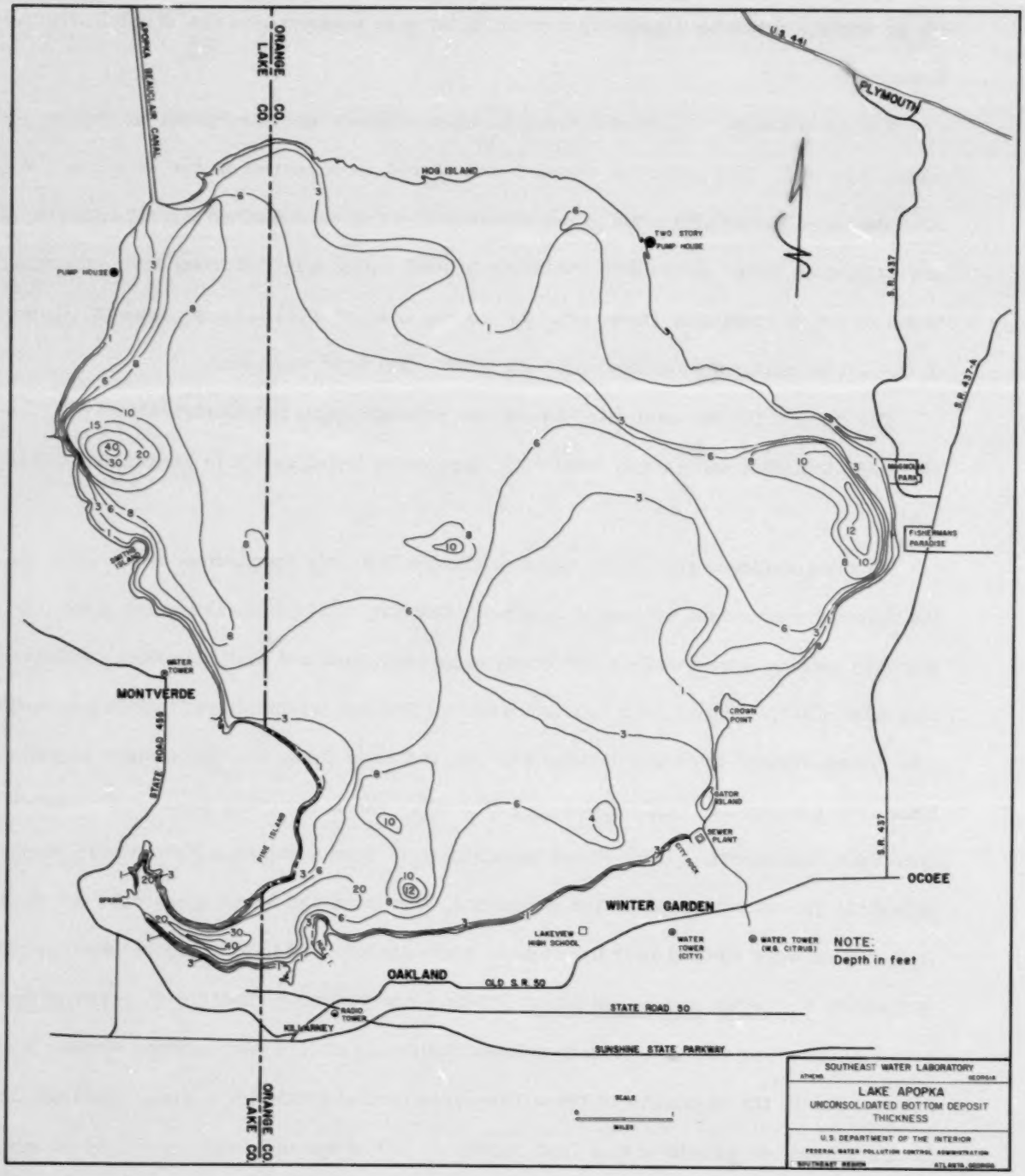

APOPKA BEAUCLAIR CANAL
ORANGE CO.
LAKE CO.
U.S. 441
PLYMOUTH
HOG ISLAND
TWO STORY PUMP HOUSE
PUMP HOUSE
S.R. 437
S.R. 437-A
MAGNOLIA PARK
FISHERMANS PARADISE
WATER TOWER
MONTVERDE
STATE ROAD 455
PINE ISLAND
CROWN POINT
GATOR ISLAND
SEWER PLANT
CITY PARK
OCOEE
WINTER GARDEN
LAKEVIEW HIGH SCHOOL
WATER TOWER (CITY)
WATER TOWER (W.G. CITRUS)
NOTE:
Depth in feet
OAKLAND
OLD S.R. 50
STATE ROAD 50
RADIO TOWER
KILLARNEY
SUNSHINE STATE PARKWAY
SCALE
MILES
SOUTHEAST WATER LABORATORY
ATHENS GEORGIA
LAKE APOPKA
UNCONSOLIDATED BOTTOM DEPOSIT THICKNESS
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHEAST REGION ATLANTA, GEORGIA

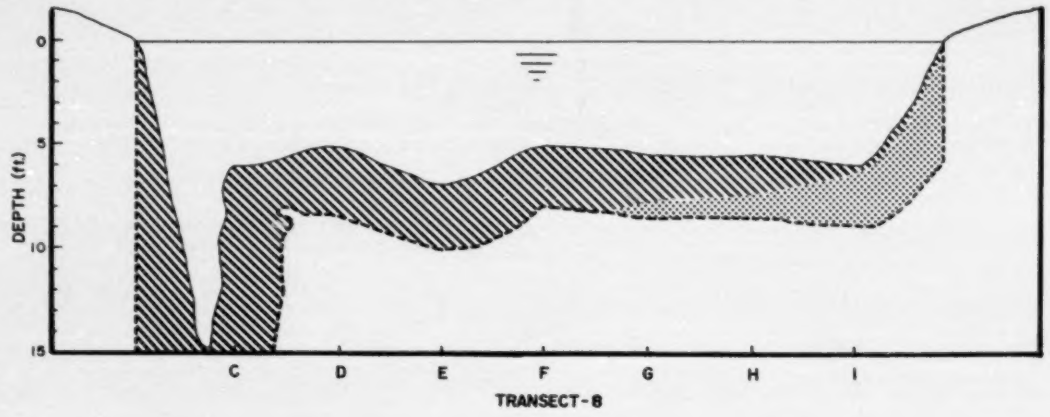
Figure 4

In addition to unconsolidated muck, deposits of sand, peat, clay and shell were also found. Water depth and bottom composition profiles for each transect line are shown in Figures 5 and 6.

A layer of a floc-like material lies immediately above the lake bottom throughout the entire lake bed. This material was not considered as a portion of the sediment core. Floc thickness varied with location and with the degree of wind-induced mixing occurring at any particular time. Anaerobic conditions prevail within this flocculent body of organic material which constantly shifts over the bottom (Lackey 1967). As a consequence, most of the bottom has been made unsuitable for benthic fish-food organisms.

The depth of the unconsolidated deposit has prevented game fish (Centrachidae) from fanning beds or finding satisfactory hard substrate for egg laying except in limited areas of the lake.

Physical evidence from core samples showed that only four bottom areas, other than the immediate shoreline, had a solid substrate. The largest of these was located in the lake's northern section, approximately 600 acres of bottom. Sand and shell underlaid a relatively thin layer of silt, and provided a solid substrate for fish food organisms and spawning grounds. The second largest area was located adjacent to Crown Point near the eastern shoreline. This area encompassed approximately 300 acres. The bottom was sand, shell, and clay covered by thin layers of floc. Gross examination of core samples collected here showed biological growth beneficial to fish production. The third and fourth areas were the smallest. These were located near the western shoreline adjacent to Pine Island. Shell bottom (primarily Viviparus georgianus altior Pilsbry) covered approximately 75 acres in each area. As much as two feet of soft sediment which has drifted over portions of these shell bottoms limits the capability of these two areas for fish production. Areas found suitable in this survey for growth of fish food organisms or fish spawning were generally the same as those presented by the Florida State Board of Health in 1964 (Burgess). Other than the



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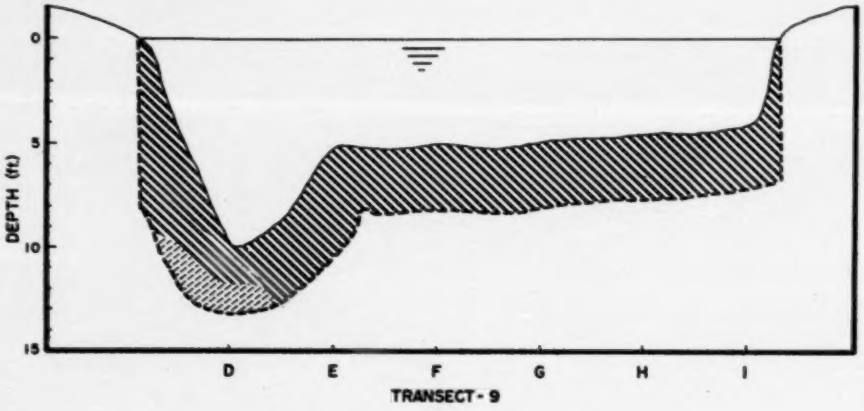

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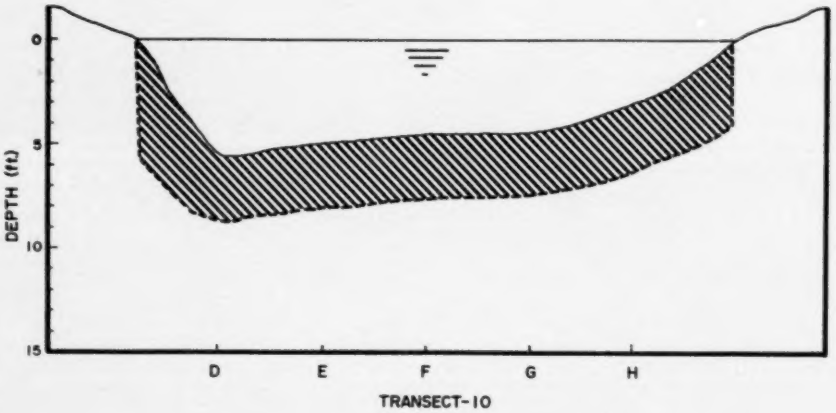

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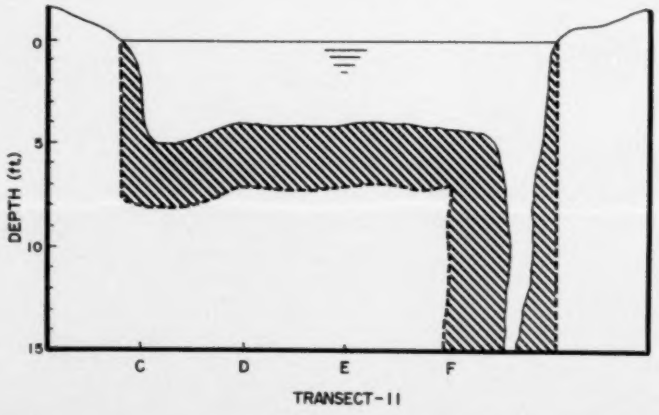
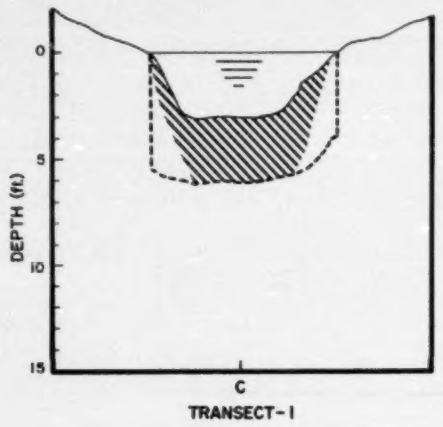


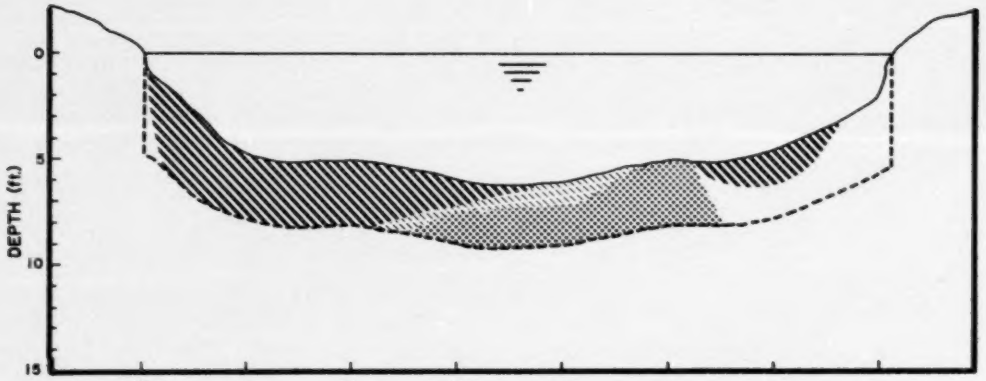
TRANSECT-11

A



TRANSECT-I

NOTE: DISTANCE BETWEEN TRANSECT POINTS EQUALS 4,000 FEET.



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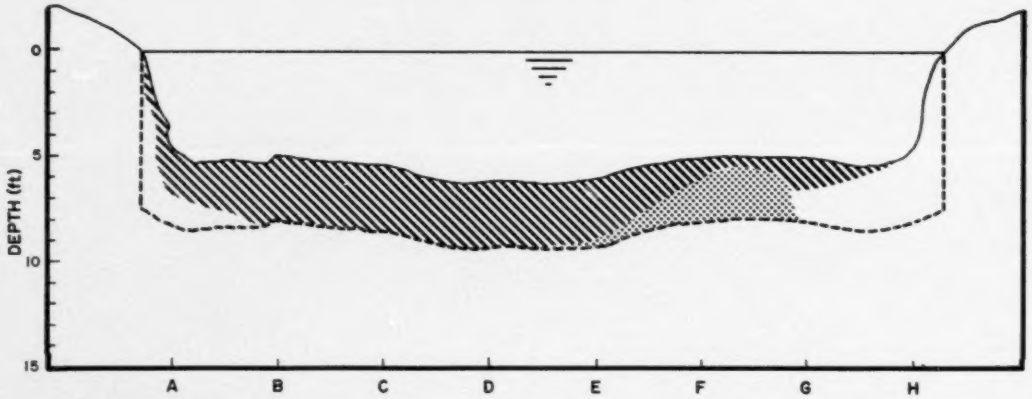


TRANSECT-3

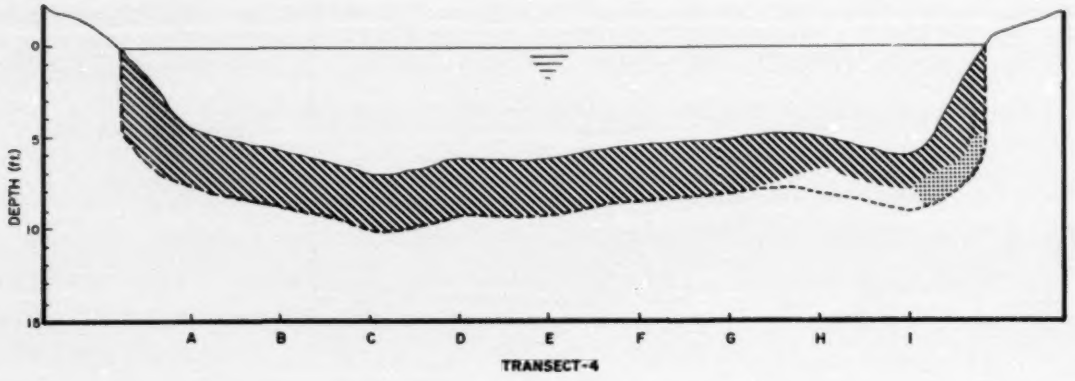
KEY

- PEAT
- MUCK
- SAND
- CLAY
- SHELL
- SAND & CLAY
- ----- LIMITS OF F.W.P.C.A. STUDY

Figure 5. Water Depth and Bottom Composition Profile for Transects I through II

B

DISTANCE BETWEEN
CT POINTS EQUALS
FEET.



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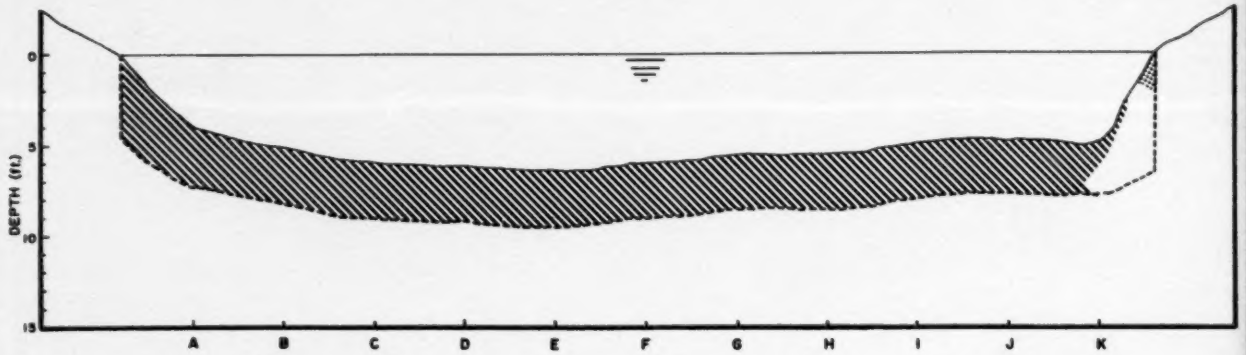

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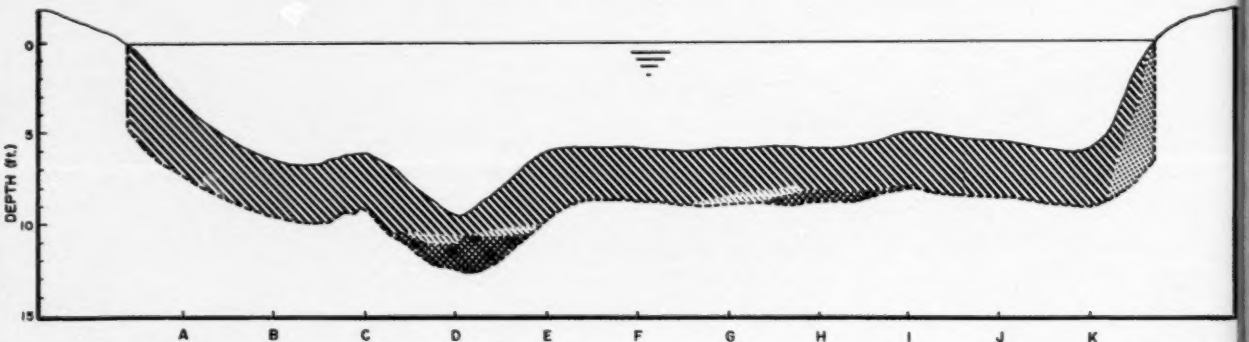

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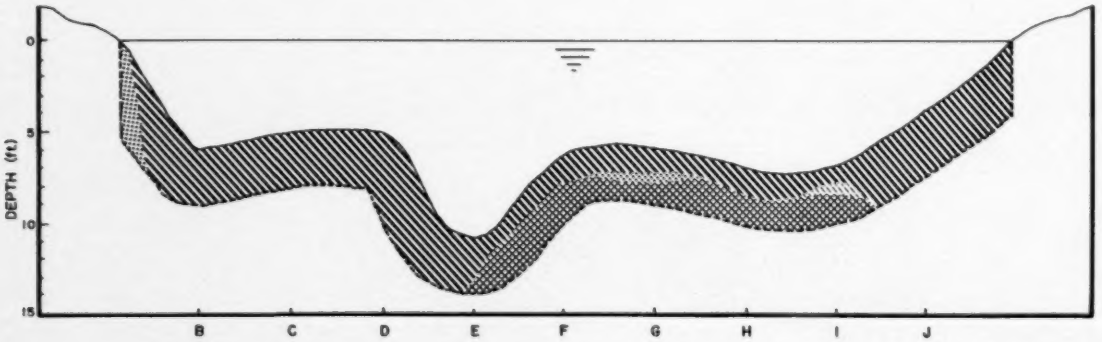

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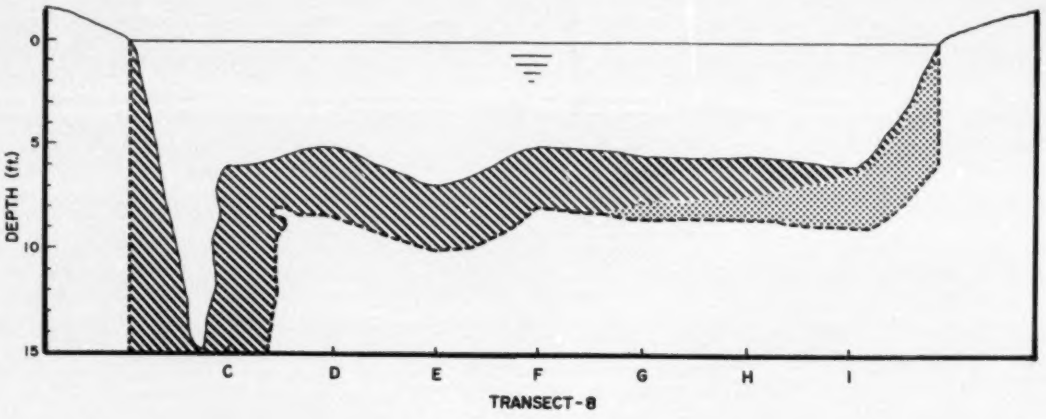

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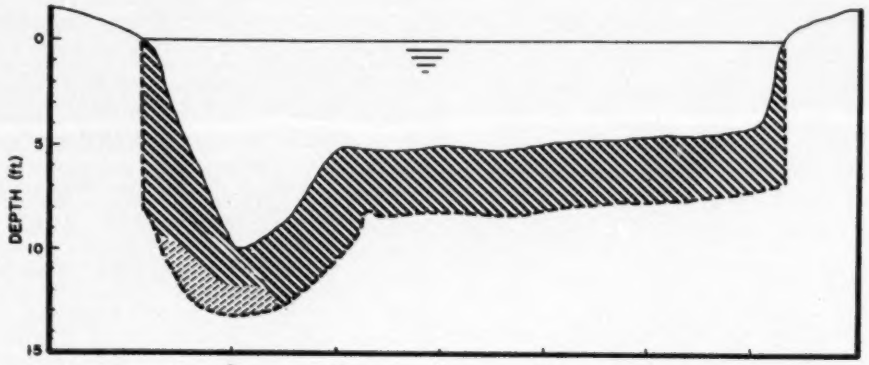

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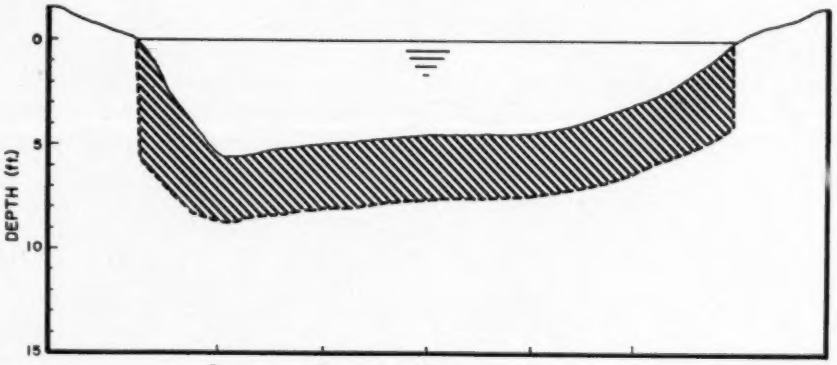

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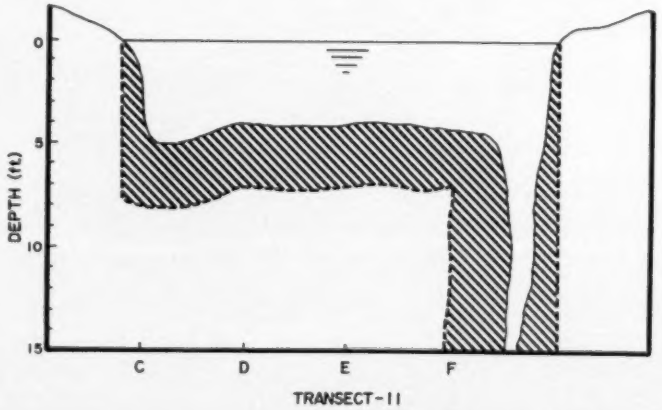

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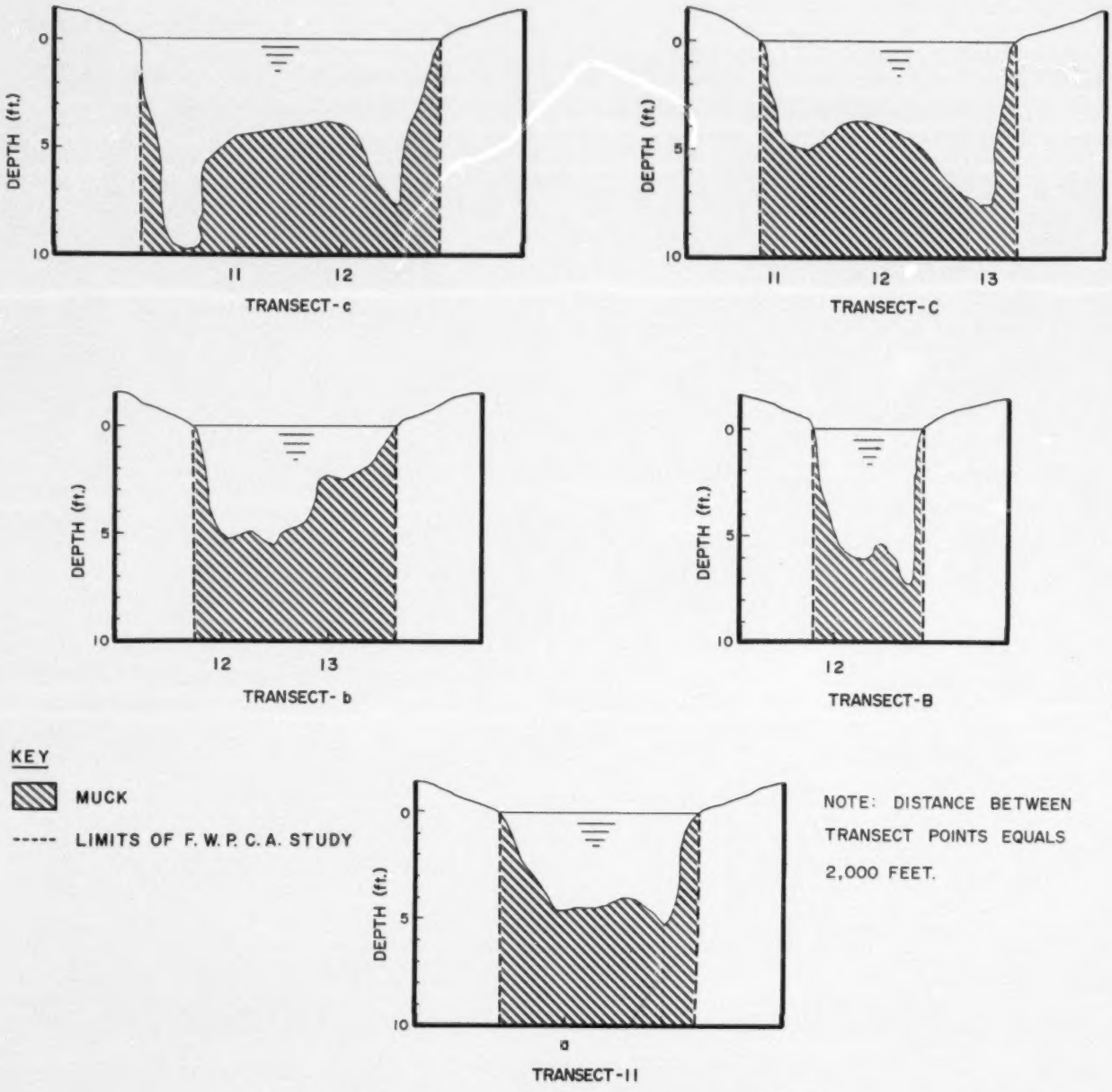


Figure 6. Water Depth and Bottom Composition Profile for Gourd Neck Transects

four areas described above, both surveys also revealed that 400 to 600 acres of the shoreline were suitable for fish production.

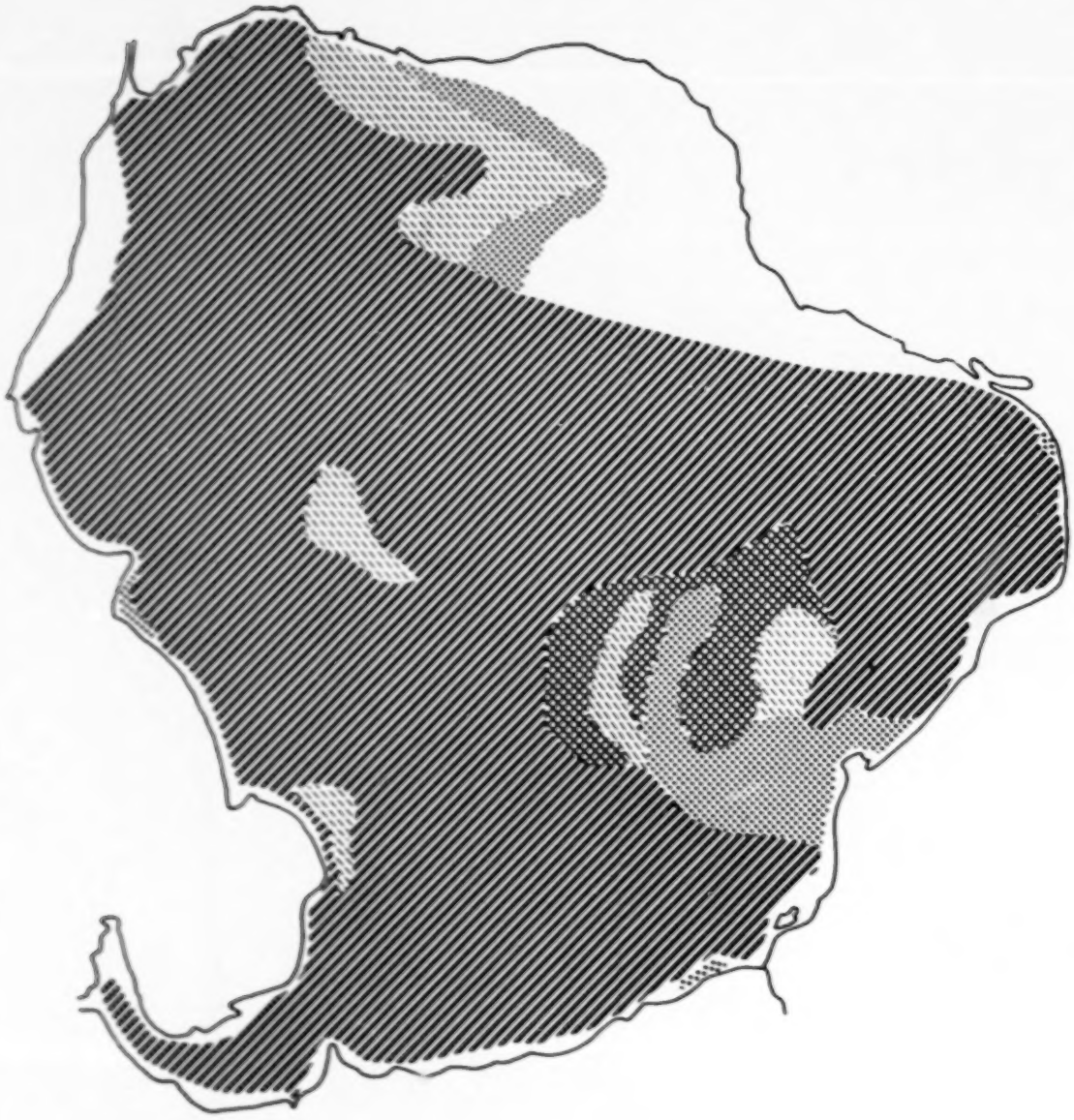
Figure 7 shows the location, type of bottom, and probable extent of solid substrate that would be exposed if one, two, or three feet of deposit were removed from the lake bottom. As the figure indicates, removal of bottom deposits to depths of as much as three feet would still leave most of the lake bottom covered with unconsolidated muck.

The bottom deposits in Gourd Neck, while of a muck-like consistency, could be distinguished from muck found in other areas of the lake. Gourd Neck muck appeared to be more like vegetative detritus, which is understandable since extensive water hyacinth stands near the spring contribute to the buildup of lake sediment.

Lake Apopka has not yet become a typically eutrophic lake in at least one respect. It does not have an extensive zone of emergent plants. The lack of attached shoreline vegetation is associated with the characteristics of lake sediments. Attachment for higher aquatic plants seems limited to a few areas in solid substrate described above. Although some attached vegetation may be able to find a holdfast in less consolidated material, the shifting of these muds by wave action apparently prevents establishment. In the absence of higher plants, the abundance of plant nutrients in the lake water is made readily available to phytoplankton. Blooms have become persistent (Lackey, 1967). The dense floating algal biomass shades underlying phytoplankton and causes them to die and sink, adding to the highly organic lake sediment. Phytoplankton density also shades some solid substrate and makes it uninhabitable for higher plant life.

CHEMICAL CHARACTERISTICS OF BOTTOM DEPOSITS

Analyses for nitrogen, phosphorus, COD, and solids were made of the bottom deposit samples to provide an estimate of the total nitrogen and phosphorus in the lake bottom, to determine the general location of these elements, and to compare chemical composition with the physical appearance of core samples. Results of chemical analyses on the lake



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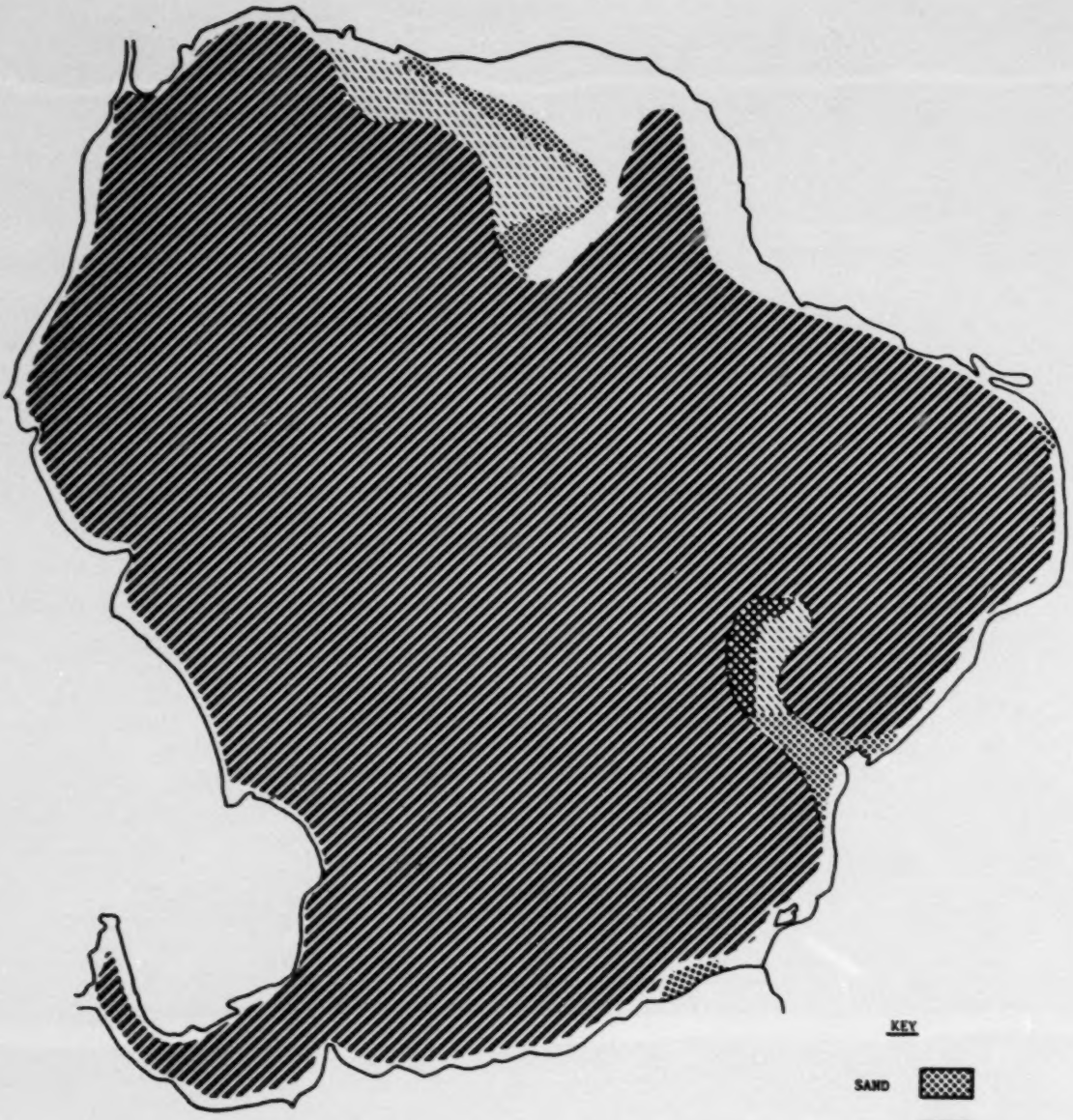

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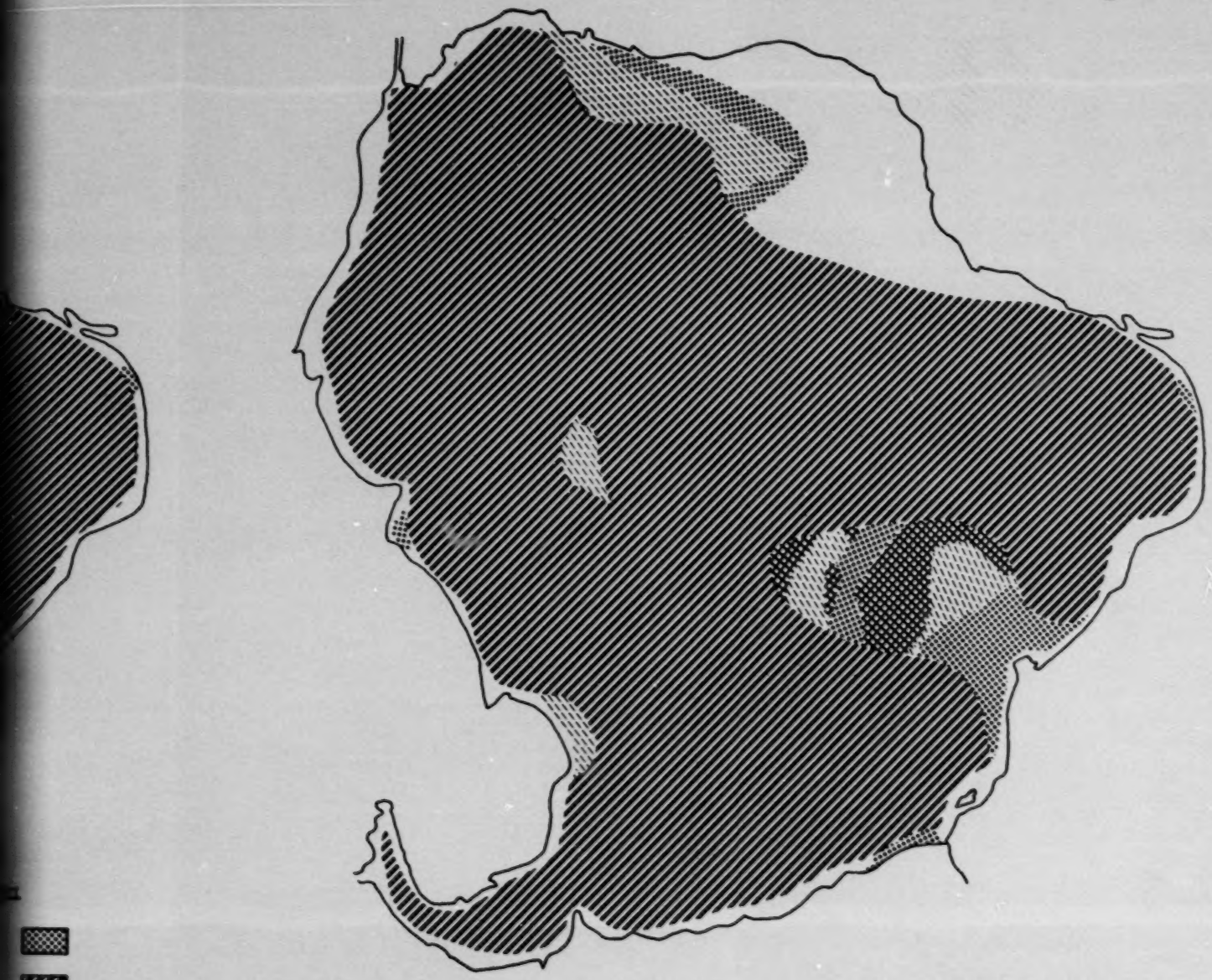


Figure 7. The Location, Type of Bottom and Extent of Solid Substrate Exposed (A) One, (B) Two, or (C) Three Feet of Overburden Removed.

sediments are found in Appendix B. It will be noted that complete analyses are not available for every transect station (See Figure 8 for location of complete analysis stations). Only solids analyses were completed for every sampling point.

Solids and Chemical Oxygen Demand

Examination of the total solids data indicated that the concentration of solids increased with depth. The highest solids values were observed in samples of shell and sand, usually between 20 and 55 percent total solids. In muck the total solids content of surficial samples seldom exceeded five percent, and then only in areas adjacent to the shoreline. At three foot depths in muck, total solids values generally ranged between 6 and 12 percent with an occasional value up to 29 percent adjacent to the shoreline.

In the important muck deposits, the volatile solids content comprised from 32 to 77 percent of the total solids and was not significantly different from one area of the lake to another. As expected, the volatile solids values were consistently related to chemical oxygen demand (COD) and correlated excellently with the description of the sample, i.e. peat was high in volatile solids, shell and sand were low, and muck was usually in between these two extremes. A correlation coefficient of 0.8 was calculated for COD versus volatile solids. Although this value does not infer excellent correlation, the relationship was considered adequate for indicating COD levels in areas where analyses were not made (calculated COD values marked with an asterisk in Appendix B). The average COD for muck samples was approximately 1100 mg/g on a dry weight basis.

Nitrogen and Phosphorus Concentrations

The total Kjeldahl nitrogen (TKN) in the samples was also related to the volatile solids. Approximately four percent of the volatile solids was composed of nitrogen. This relationship was constant for all types of samples from all areas of the lake, and for this reason a

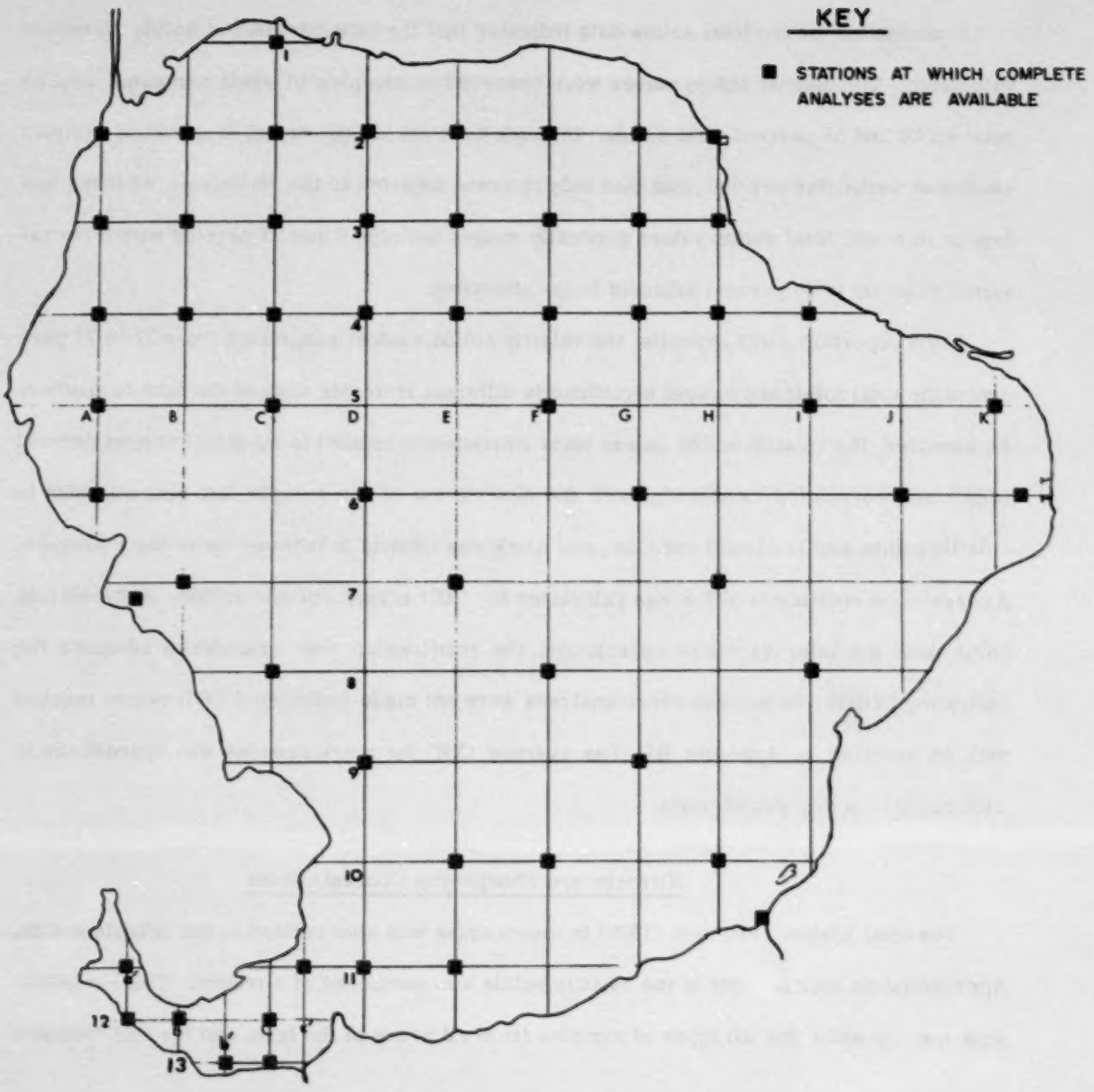


Figure 8. Stations Having Complete Chemical Analyses.

factor was used to compute TKN from the volatile solids for approximately half of the samples (see Appendix B).

Total Kjeldahl nitrogen values on a wet basis for the muck ranged between 0.2 and 3.7 mg/g, while dry weight values were generally between 11 and 43 mg/g (1 to 4 percent). The more assimilable forms of nitrogen, i.e. nitrite, nitrate, and ammonia, constituted only a few percent of the total nitrogen. Ammonia nitrogen was usually less than five percent of the TKN value, and nitrite and nitrate values were less than one percent of the ammonia nitrogen.

The phosphorus picture was more complex than the nitrogen. A few special analyses indicated that relatively high concentrations of phosphorus were associated with samples having the lowest total solids. 1/

Conversely, the nitrogen in the bottom deposits was associated largely with solids. Development of a suitable correlation between phosphorus and solids content was not possible.

Complicating the phosphorus characterization further was the fact that the analytical method for phosphorus was known not to digest all forms of phosphorus to orthophosphate, the form in which it is detected chemically. The method selected for phosphorus determinations (see previous section) was the one that yielded the highest results of several digestion techniques investigated. On a wet basis, total phosphorus (as P) in the muck samples ranged between 8 and 121 mg/kg. Translated to a dry basis, the range was usually from 200 to 2000 mg/kg (0.02 to 0.21 percent). One high value of 4000 mg/kg was found at the mouth of the stream receiving sewage treatment effluent from Winter Garden.

Peat deposits were encountered in less than ten percent of the core samples. The nitrogen, phosphorus, and solids content of the peat was slightly higher than that of the muck.

1/ Several samples of upper core material were filtered, and the filtrates contained up to 10 mg/1 of orthophosphate.

Nutrient Distribution

The top three feet of sediments in the bottom of Lake Apopka were estimated to contain approximately one half billion pounds of nitrogen (all forms) and five to ten million pounds of phosphorus. Nitrogen was located uniformly throughout the lake bottom except in areas that were predominately shell or sand, which contained less. The phosphorus was generally present in all muck core samples to about the same extent, dry weight concentrations decreasing rapidly between the top and middle core segments. Figures 9 and 10 show the distribution of surficial nitrogen and phosphorus, respectively, throughout the lake. Only dry weight values are indicated. As the figures show, no particular section of the lake had exceptionally higher nitrogen or phosphorus content than any other. This finding would discount the feasibility of selective removal of nutrient-rich deposits. Removal is further discouraged by the depth of the unconsolidated deposits, which averaged 5 feet.

A few comparatively low nutrient values were non-uniformly distributed over the lake. Usually these low values were associated with sand or types of deposits other than muck or peat.

Nitrogen-Phosphorus Ratios

Nitrogen-phosphorus (N-P) ratios for the muck and peat had generally the same value range, as low as 9 and over 120 at times. The average ratio was approximately 50, a high value. With few exceptions, N-P ratios were observed to increase from surface to mid-depth of the sample cores. This could be interpreted as evidence of a greater need for phosphorus (compared to nitrogen) on an exchange basis at the sediment-water interface. As the lake ecosystem now exists, nitrogen is not limiting since the predominate blue-green algae are capable of fixing atmospheric nitrogen.

Nutrient Recycling

Measurement of the exchange rate of nutrients at the sediment-water interface was con-

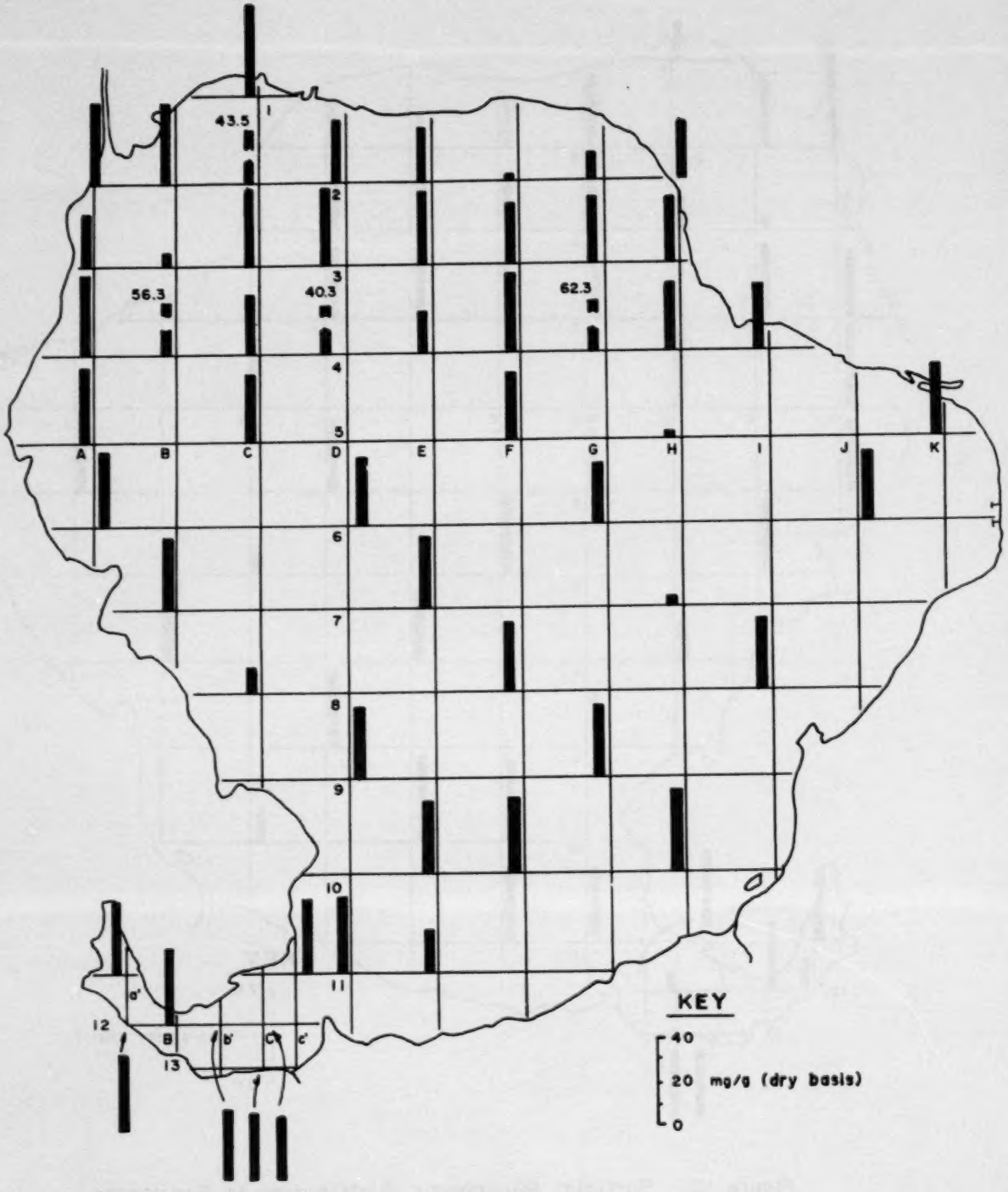


Figure 9. Surficial Nitrogen Distribution in Sediments.

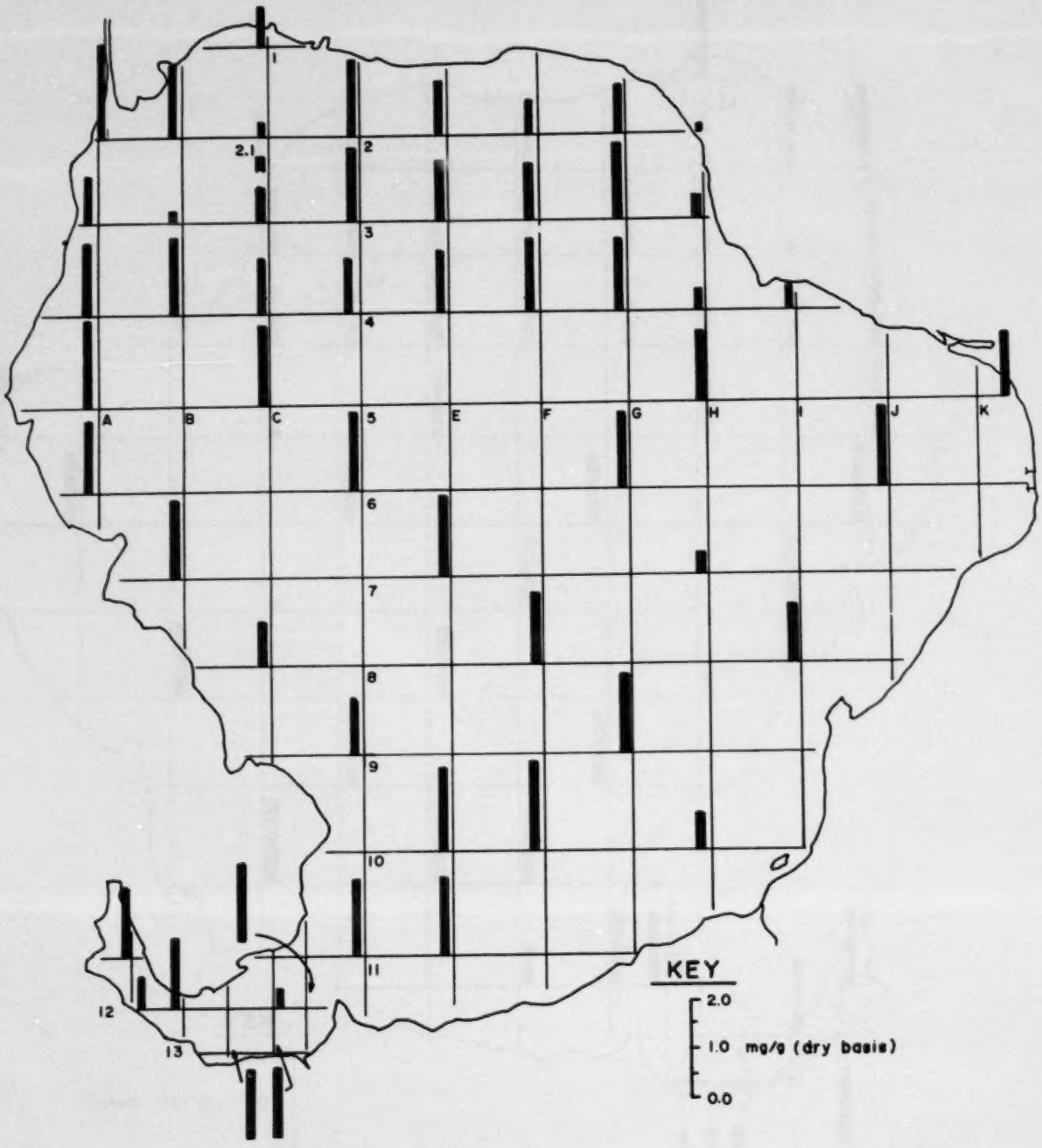


Figure 10. Surficial Phosphorus Distribution in Sediments.

sidered beyond the scope of this study. However, we feel that bottom deposits are important sources of nitrogen and phosphorus. One of the few recent studies concerning the nitrogen exchange phenomenon was done by Kuznetsov (1968). It seems important to mention some specific findings reported by Kuznetsov because he studied a lake with bottom deposits physically similar to the deposits found in Lake Apopka. Kuznetsov found that practically all muds in the Rybinsk Reservoir (Russia) released nitrogen into the lake waters. The gray silts (similar to the muck of Apopka) of the former river bed released as much as 30 mg/m^2 of nitrogen per day. Denitrification was also observed over all deposits except sand. The daily rate of denitrification over peat was as high as 4 mg/m^2 of bottom area. Similar trends can conceivably occur in Lake Apopka.

Wet Versus Dry Basis

In the preceding discussion on concentrations of nitrogen and phosphorus in Lake Apopka sediments, both wet weight and dry weight values are shown. The reasons for this are twofold. First, wet weight values provide information on the amount of nutrients which could be removed in a given volume if dredging was determined desirable as a restoration measure. Nitrogen content on a wet basis generally increased with sediment depth. Most wet weight phosphorus values also increased with depth but not so pronounced as did nitrogen. Secondly, dry weight concentrations provide a means of comparing the enrichment of Lake Apopka bottom deposits with that of other lakes. Table 1 shows such a comparison. It should be noted that except for Lake Tahoe, the other compared lakes have experienced problems associated with eutrophication. The table indicates that Lake Apopka sediments have the highest amount of nitrogen. And, the maximum value for phosphorus is greater than found at either the Madison Lakes or Lake Sebasticook.

No published information was found on sediment nitrogen and phosphorus values for other lakes in Florida. Unconsolidated sediments in Lake Apopka do appear to be unnaturally rich in nitrogen, however, although not so much so in phosphorus. The possibility that the Apopka

TABLE 1

A COMPARISON OF NITROGEN AND PHOSPHORUS CONTENT FOR SEVERAL LAKES

NAME OF LAKE	ORG. N (mg/kg) (dry weight)	TOTAL P (mg/kg) (dry weight)	TYPE OF BOTTOM SAMPLE	REFERENCE
Madison Lakes, Wis.	7000-9000	1000-1200	"bottom muds"	(Sawyer, 1945)
Green Lake, Wash.	7000	1670	"uppermost layer"	(Sylvester and Anderson, 1964)
Lake Sebasticook, Maine	3000-18,000	600-1600	"lake-bed sediments"	(Mackenthun et al, 1968)
Lake Tahoe, Calif.-Nev.	60-16,600	--	"upper 10 cm"	(McGauhey et al, 1963)
Lake Apopka, Fla.	10,000-40,000 (26,000 average)	200-2000	Muck deposits to depths of 1 meter	--

sediments would contribute substantial amounts of nutrients to the lake once other nutrient inputs are controlled is quite likely.

CHEMICAL CHARACTERISTICS OF CERTAIN NITROGEN AND PHOSPHORUS SOURCES

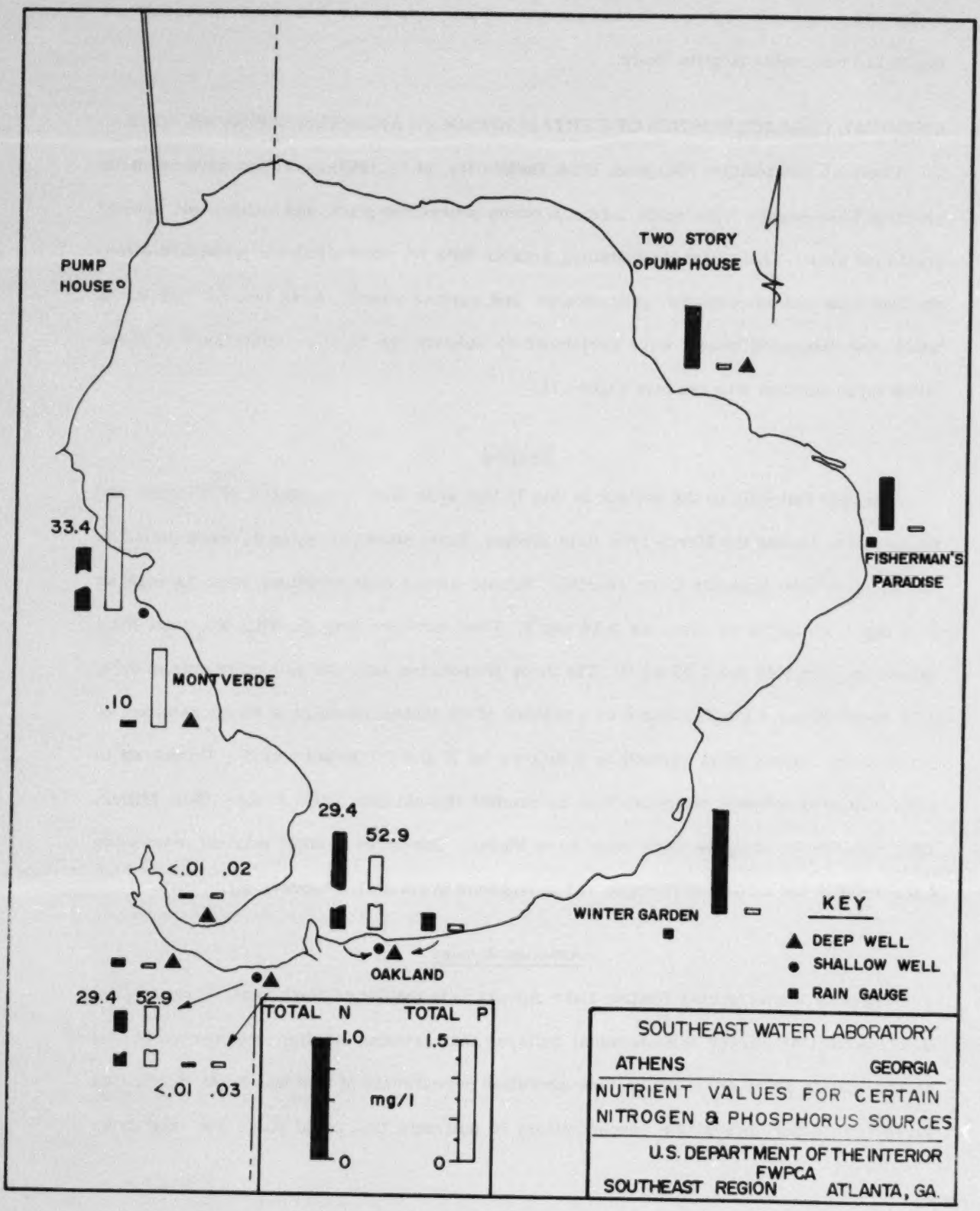
Previous publications (Burgess, 1964; Huffstutler, et al, 1965) have discussed nutrients entering Lake Apopka from muck farms, a citrus processing plant, and a municipal sewage treatment plant. These reports contained meager data on plant nutrients transported into the lake from the atmosphere, groundwater, and surface runoff. Analyses, the results of which are discussed below, were performed to indicate the relative importance of these latter three nutrient sources (see Figure 11).

Rainfall

The rain that falls on the surface of this 30,000 acre lake is a source of nitrogen and phosphorus. During the March 1968 field studies, three rainwater samples were collected for analysis (see Appendix C for results). Nitrate-nitrite concentrations were as high as 0.78 mg/1, ammonia as much as 0.14 mg/1. Total nitrogen (org. N, NH_3, NO_3, and NO_2) ranged between 0.42 and 1.08 mg/1. The three phosphorus analyses yeilded results of 0.01, 0.08, and 0.09 mg/1 (as P). Based on a rainfall of 50 inches annually, a rough estimate of the nutrient loading from rainfall is 6 lb/acre/yr N and 0.7 lb/acre/yr P. Compared to other reported nutrient concentrations in rainfall (Hutchinson, 1957; McKee, 1962; Miller, 1961) the Apopka samples were equal to or higher. Compared to other nutrient sources in Lake Apopka, the amount of nitrogen and phosphorus in rainwater appears significant.

Artesian Aquifer

The only known spring feeding Lake Apopka is in the Gourd Neck area. However, the U. S. Geological Survey (Knochenmus) believes that artesian aquifer seepage occurs at several points along the southwestern shoreline (no estimate of flow was made during this survey). In order to evaluate concentrations of nutrients that could enter the lake from


PUMP HOUSE
TWO STORY PUMP HOUSE
33.4
FISHERMAN'S PARADISE
MONTVERDE
.10
29.4
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WINTER GARDEN
KEY
DEEP WELL
SHALLOW WELL
RAIN GAUGE
OAKLAND
29.4 52.9
<.01 .03
TOTAL N
TOTAL P
1.0
1.5
mg/l
0
0
SOUTHEAST WATER LABORATORY
ATHENS GEORGIA
NUTRIENT VALUES FOR CERTAIN NITROGEN & PHOSPHORUS SOURCES
U.S. DEPARTMENT OF THE INTERIOR
FWPCA
SOUTHEAST REGION ATLANTA, GA.

Figure 11.

artesian groundwater sources, water samples were collected from the spring and from deep wells in the Floridian Aquifer. The values from the spring were greater, indicating contamination of the sample by eddy currents which mix lake and spring water. Except for one sample taken from a deep well at Monteverde Academy, waters from the artesian aquifer in the southwest lake area had nutrient values (for four samples) that ranged from 0.10 to 0.16 mg/1 N and 0.01 to 0.06 mg/1 P. The Monteverde well sample had total N and P values of 0.10 mg/1 and 0.85 mg/1 respectively. Some surface contamination of this well could be occurring.

A sixth artesian sample taken near the northeast shoreline at Hooper Farms (muck farm) had a total nitrogen value of 0.52 mg/1 and a total phosphorus value of 0.03 mg/1, much higher nitrogen than found in the other artesian well samples.

Citrus Grove Drainage

Most runoff from the watershed surrounding the lake appeared to be subsurface. The sandy soil allowed rainfall to infiltrate readily, but not to pool. No quantitative estimate was made of the nutrients seeping into the lake through this subsurface source. However, the concentration of nitrogen and phosphorus in subsurface runoff from some of the citrus groves was determined for a few samples. Samples filtered (0.45 u membrane filter) after acidifying [1/] had values for nitrate-nitrite (as N) as high as 30.6 mg/1, and phosphate (as P) ranged as high as 52.9 mg/1. Some recent fertilization of the groves could have occurred during the month of March.

The relative amounts of nitrogen and phosphorus in rainwater, artesian groundwater, and subsurface runoff from orange groves have been indicated by the above data. No attempt was made to perform an exhaustive study of these sources, but the results obtained from limited sampling suggest that they need to be considered in any control program.

[1/] A more desirable analytical technique would be to filter prior to acidifying. As reported here, the nitrogen and phosphorus values are essentially totals and should not be considered as the dissolved fractions.

AVAILABLE NITROGEN AND PHOSPHORUS DATA

While determining what studies were to be performed by FWPCA in the March survey, all past data available on nitrogen and phosphorus sources and sinks were compiled for evaluation. Table 2 has been developed from both the compilation of past data and from the FWPCA studies to indicate what nitrogen and phosphorus information is currently available to the Technical Committee. [1/] The table has been developed in narrative form and should be read closely for it contains details not discussed elsewhere in this report.

A nutrient balance for Lake Apopka is considered to be a high priority item. Before an adequate plan for nutrient removal and restoration of the lake can be formulated, such a balance should be made, although some sources or sinks may be judged insignificant or indeterminable. The balance should be used to select the most important sources of nutrient input and those most amenable to control. Information on losses of nitrogen and phosphorus now occuring within the system may indicate avenues of approach for nutrient removal. Nutrients other than nitrogen and phosphorus are not felt to be important at this time.

Table 2 shows what further data are needed in order to make a complete nitrogen and phosphorus balance. Some studies are underway to obtain these additional data. It is felt that the Technical Committee now has, will soon have, or can easily obtain the information needed to consider restoration measures for Lake Apopka.

[1/] Some additional data have been collected since the FWPCA field studies in March which would further updata this table. These data are available in the office of the Orange Conservation Department, Orlando, Florida.

TABLE 2

AVAILABLE DATA AND NEEDS FOR A NITROGEN AND PHOSPHORUS BALANCE IN LAKE APOPKA

NITROGEN AND PHOSPHORUS INPUT

SOURCE	DAILY AMOUNT	ADDITIONAL DATA NEEDED
1. Municipal waste	75 lb/day total N 19 lb/day total P (Huffstutler, et al, 1965)	---
2. Industrial waste	192 lb/day total N 9.6 lb/day total P (Huffstutler, et al, 1965)	---
3. Agricultural waste		
(a) Muck farms	1600-16,000 lb/day total N 65-650 lb/day total P (Huffstutler, et al, 1965)	Update, especially for seasonal variation.
(b) Citrus farms	Not known. [FWPCA well point samples (three) showed total N ranging from 4.54 to 33.40 mg/l while total P ranged from 1.4 to 52.9 mg/l. These are high concentrations which portend a possible high nutrient input from this source. There is no information, however, on quantity of ground water from citrus and other peripheral areas entering the lake.]	Need more analytical data and flow data on near surface flow from citrus and other areas on the lake's periphery.
4. Nitrogen fixation by blue-green algae	Not known.	Estimate from past biological studies and supplement by future studies.
5. Natural sources		
(a) Rain directly on lake	Based on an annual rainfall of 50 inches and using only three FWPCA rainwater analyses, the nutrient contribution from this source is estimated to be: 500 lb/day N, 57 lb/day P.	Additional samples throughout year.

NITROGEN AND PHOSPHORUS INPUT (Cont'd)

SOURCE	DAILY AMOUNT	ADDITIONAL DATA NEEDED
(b) Artesian aquifer	Not known. [FWPCA analyses of four artesian wells located near Gourd Neck Spring 1/ showed a range of: Total N, 0.1 - 0.16 mg/l Total P, 0.01 - 0.06 mg/l In terms of concentration, the artesian aquifer seems to introduce the lowest amounts of N and P into the lake. One sample from an artesian well in the muck farms showed a much higher N concentration, 0.52 mg/l total N (0.03 mg/l total P). There is some indication here that lake water could be recharging the aquifer.]	Flow estimate needed in order to calculate loading. Need further hydrologic information as to possibility of lake recharging the artesian aquifer.
(c) Surface runoff	Not known. [Not to be confused with subsurface runoff from citrus groves.]	Flow and nutrient concentration data.
6. Recycling of nutrients from sediments (This is not a direct nutrient input as the lake now exists, but it is most important to eventual lake restoration).	Not known. [Nutrient and organic characterization of sediments available in this report. Most experts agree that this can be an important nutrient source when and if point source nutrient pollution is eliminated.]	Research on nutrient recycling.

1/ A sample taken from deep within Gourd Neck Spring had 1.40 mg/l total N and 0.07 mg/l total P. Eddy-induced mixing with lake water was felt to have produced values higher than found in the artesian aquifer samples.

NITROGEN AND PHOSPHORUS OUTFLOW

SOURCE	DAILY AMOUNT	ADDITIONAL DATA NEEDED
1. Denitrification in water and sediments	Not known.	Possible gas release study.
2. Insect emergence	Negligible	-
3. Fish harvesting	Negligible	-
4. Weed removal	Negligible	-
5. Irrigation water	Not known. [Lake water N and P concentration data available but not flow data.]	Flow measurements
6. Outflow through Beauclair Canal	2000 lb/day N 54-540 lb/day P [rough estimate based on data from several sources. Average flow estimated as 100 cfs.]	More accurate estimate from existing data.
7. Fixation of nutrients in sediments	Not known. [More nutrients believed entering sediments than leaving at the present time.]	Research or determination by difference.
8. Near surface outflow (not recharge of artesian aquifer)	Not known. [May or may not be possible that ground water flows from lake.]	Flow and nutrient concentration data.

NITROGEN AND PHOSPHORUS WITHIN THE LAKE

Data are available in the files of the Orange County Conservation Department.

The volume displacement time for Lake Apopka has been estimated as 2 1/2 years.

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APPENDIX A

METHODS FOR LABORATORY ANALYSIS OF SEDIMENTS

METHODS FOR LABORATORY ANALYSIS OF SEDIMENTS [1]

Frozen sediment samples were allowed to thaw, transferred to Sorvall high speed blender cups and blended until an emulsion free of discernible fibers was formed. No shells, fibers, or other materials were removed from samples prior to blending. Samples were then poured into new plastic containers and stored in a refrigerator.

CHEMICAL OXYGEN DEMAND

Three grams of the homogenized, wet sample was washed into a one liter volumetric flask and brought up to volume with water. A magnetic stirrer, operating at high speed, was used to suspend the emulsified sample uniformly throughout the flask while a sample equivalent to 0.15 grams was taken with a transfer pipet. Analyses were performed by the dichromate method (APHA, 1967). Average differences for duplicates were 0.29 mg/g for the 15 to 30 mg/g range, 1.3 mg/g for the 40 to 70 mg/g range, 1.4 mg/g for the 80 mg/g range, and of 1.7 mg/g for the values above 100 mg/g.

TOTAL AND VOLATILE SOLIDS

A homogenized, wet sample was weighed into a predried, preweighed crucible, dried overnight at 105°C and weighed. Percent total solids is represented by the dry weight X 100 divided by the original weight.

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[1] The methods descriptions in this section are general. The procedures described closely follow those found in the Chemistry Laboratory Manual for Bottom Sediments compiled by the Great Lakes Region Committee on Analytical Methods (U. S. Dept. Interior, 1968).

Samples were then placed in a muffle furnace at 600°C for one hour and weighed again. Percent volatile solids is 100 times the difference between the dry weight and weight after ignition at 600°C divided by the original weight.

TOTAL KJELDAHL NITROGEN

One gram of the homogenized, wet sample was transferred to a Kjeldahl flask. A digestion mixture of sulfuric acid, potassium sulfate and a mercury catalyst were added, and the mixture was heated until the solution remained clear with copious evolution of sulfuric acid fumes. Sodium hydroxide was added until the mixture was alkaline to phenolphthalein. The ammonia was distilled into boric acid solution and titrated with sulfuric acid. Average differences for duplicates were 0.026 mg/g in the 0.4 to 1 mg/g range, 0.1 mg/g in the 1 to 2 mg/g range, and 0.2 above 2 mg/g. Results were computed as mg N/g of wet sample.

NITRATE-NITRITE NITROGEN

A ten gram homogenized, wet sample was boiled in 50 mg 0.1 N H_2SO_4 for fifteen minutes. The mixture was filtered through a membrane filter and the filtrate was analyzed on the Technicon AutoAnalyzer by the cadmium reduction column and the sulfanilamide naphthylethylenediamine method. Results were computed as mg N/kg wet sample.

TOTAL PHOSPHATE ANALYSIS

After other analyses were completed, the total remaining sample was transferred to a crucible and dried at 100°C for 24 hours. The residue was then powdered with a mortar and pestle and a sample was weighed and transferred to a 250 ml Erlenmeyer flask. Three ml

sulfuric acid and five ml nitric acid were added and the solution was allowed to boil on a hot plate until charring began. Nitric acid was then added in 5 ml quantities until there was no further charring. The mixture was then boiled until copious white fumes were evolved.

After digestion, the solution was transferred quantitatively through a membrane filter and a resin column to remove particulate matter and iron. The filtrate was analyzed by the molybdenum blue method using the AutoAnalyzer. Results were computed as mg P/g wet sample.

APPENDIX B

PHYSICAL AND CHEMICAL CHARACTERISTICS OF CORE SAMPLES

STA-TION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
1C	3	38	3" floc	T	38	1000	2.1	3.8	1.7	43.1	0.17	57	32	822	53
			35" muck	M	61	1130	3.9	5.4	1.1	19.6	0.10	74	24	444	46
				B	70	1170	4.3	6.0	1.5	24.5	0.13		23	278	65
2A	1	14	5" floc	T	22	1380	1.3	1.6	0.6	37.0	0.15		33	2010	
			1" muck(1)	M	67	1050	4.4	6.4	1.8	27.2	0.42		139	2177	13
			8" peat	B	146	1490	9.2	9.8	3.0	30.8	0.17		20	200	
2B	5	38	5" floc	T	22	1100	1.4	2.0	0.7	36.5	0.16		31	1533	23
			33" muck	M	86	1150	4.1	7.5	1.6	20.8	0.32	38	33	433	48
				B	92	1200	5.4	7.7	2.2	30.6	0.40		25	355	88
2C	5	40	5" floc	T	5	630	0.6	0.8	0.3	43.4	0.13		3	333	100
			35" muck	M	21	300	5.2	7.0	2.0	28.9	0.27		24	344	83
				B	3[illegible]	550	5.1	6.9	2.1	29.9	0.16	42	24	355	88
2D	6	15	1" floc	T	23	960	1.5	2.4	0.7	29.4	0.24		38	1577	
			11" muck	M	36	440	5.5	8.2	2.2	26.8	0.27		18	222	122
			3" shell	B	33	90	3.5	35.2	1.1	3.0	0.52		195	555	
2E	6	11	1" floc	T	26	870	1.7	3.0	0.7	22.9	0.14		34	1111	
			10" shell	M	83	1000	5.3	8.3	1.8	21.5	0.25		37	444	47
				B	34	60	2.4	56.0	0.9	1.6	0.30				
2F	5	10	6" floc	T	30	240	2.9	12.5	0.7	2.8	0.18		90	722	8
			4" sand	M	18	300	1.1	6.0	0.5	0.7	0.18		86	144	
				B	27	390	2.3	6.9	0.6	0.9	0.45		115	166	5
2G	4½	19	1" floc	T	34	710	2.9	4.8	0.5	11.0	0.15		48	1000	
			17" muck	M	62	870	4.7	7.1	2.1	29.9	0.10		43	600	49
			1" peat	B	199	1840	8.0	10.8	3.2	29.8	0.12		24	222	
2H	2	30	30" peat	T	144	960	11.1	15.0	4.0	27.1	0.13		187	1250	
				M	153	1150	9.4	13.3	3.3	25.0	0.23		56	422	59
				B	133	910	9.6	14.6	3.1	21.5	0.20		79	544	

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
3A	5	26	25" muck	T	16	500	1.7	3.2	0.8	23.8	0.16		34	1044	24
			1" peat	M	45	540	6.0	8.4	1.6	18.6	0.19	36	49	577	33
				B	97	900	8.1	10.8	2.8	26.4	0.26		97	900	29
3B	5	32	3" floc	T	14	160	7.8	8.6	0.5	5.6	0.26		21	244	24
			29" muck	M	16	230	5.1	7.0	2.0	27.9	0.16	98	49	689	41
				B	69	1110	4.4	6.2	1.9	30.2	0.17	98	38	611	
3C	5½	30	2" floc	T	16	1077	1.1	1.5	0.6	39.2	0.16		40	2066	15
			28" muck	M	17	940	1.2	1.8	0.7	37.2	0.16		30	1666	23
				B	56	900	3.9	6.2	1.2	19.9	0.16		68	1100	18
3D	6	36	5" floc	T	47	960	3.0	4.9	1.9	39.4	0.45		76	1555	25
			31" muck	M	89	1240	5.4	7.2	2.2	29.9	0.21		27	378	81
				B	87	1090	5.4	8.0	1.6	20.3	0.31		35	444	46
3E	6	32	2" floc	T	19	790	1.4	2.4	0.6	27.3	0.18		30	1255	20
			29" muck(1)	M	86	1050	5.3	8.2	2.0	24.2	0.25		29	355	69
			1" sand(1)	B	62	250	4.3	24.6	1.4	5.5	0.18		117	477	12
3F	5	10	1" floc	T	24	900	1.5	2.7	0.7	26.0	0.10		32	1166	
			8" muck	M	49	390	3.1	12.5	1.2	9.9	0.19		49	388	24
			1" sand	B	43	100	3.0	42.6	1.0	2.3	0.27		194	455	
3G	5	24	2" floc	T	18	720	1.7	2.5	0.8	30.8	0.18		41	1599	
			18" muck(1)	M	83	1040	5.0	8.0	2.1	25.9	0.24		35	433	60
			4" peat	B	152	1050	11.1	14.5	3.5	23.8	0.30		24	166	59
3H	5	6	1" floc	T	77	850	5.4	9.1	2.6	28.8	0.56		44	489	
			1" shell	M	113	1660	6.2	6.8	3.1	45.3	0.16		14	200	
			4" peat	B	150	1440	9.7	10.4	3.4	32.6	0.25		14	133	243

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
4A	4½	33	8" floc	T	27	1080	1.7	2.5	0.9	37.0	0.11		36	1444	25
			25" muck(1)	M	60	1130	3.8	5.3	1.6	30.1	0.06		25	466	64
				B	77	1260	4.4	6.1	1.8	29.5	0.09		26	477	69
4B	5½	40	10" floc	T	5	1000	0.4	0.5	0.3	56.2	0.11		8	1577	38
			30" muck	M	61	1130	3.8	5.4	1.7	30.9	0.14		30	544	57
				B	74	1250	4.1	5.9	1.9	32.7	0.05		32	544	59
4C	7	36	8" floc	T	24	860	1.7	2.8	0.7	25.7	0.10		34	1222	21
			28" muck	M	87	1210	5.3	7.2	2.2	30.4	0.09		31	433	71
				B	91	1180	5.6	7.7	2.5	32.5	0.10		32	411	69
4D	6	33	6" floc	T			2.0	3.8	1.5	40.3	0.14		47	1529	32
			27" muck(1)	M			6.0	10.1	2.4	23.9	0.20		45	444	53
				B			6.1	9.2	2.4	26.1	0.13		33	355	73
4E	6	37	6" floc	T	21	540	2.5	3.9	0.7	18.5	0.19		51	1310	14
			31" muck(1)	M	79	720	5.3	11.0	2.2	20.4	0.31		61	555	39
				B	76	480	5.1	16.0	1.8	11.2	0.26		76	478	24
4F	5½	37	9" floc	T	26	930	1.8	2.8	1.0	34.6	0.08		43	1521	23
			28" muck(1)	M	71	1030	4.5	6.9	2.0	28.4	0.17		30	444	67
				B	96	1040	6.1	9.2	2.1	23.0	0.14	42	56	611	38
4G	5	31	10" floc	T	22	1220	1.2	1.8	1.1	62.2	0.13	40	28	1532	39
			21" muck	M	70	800	4.4	8.8	2.0	23.2	0.14		66	755	30
				B	89	1090	5.6	8.2	1.9	22.7	0.04		36	433	53
4H	5	28	5" floc	T	90	1070	6.0	8.4	2.5	29.2	0.06		30	355	
			22" muck(1)	M	28	900	2.0	3.1	1.1	34.6	0.07		12	1388	92
			1" peat	B	128	600	10.0	21.2	2.9	13.7	0.02		94	444	
4I	6	22 1/8	2" floc	T	100	1040	6.0	9.6	2.8	28.6	0.17		44	455	
			19" muck	M	32	900	2.1	3.6	0.9	24.8	0.11		15	433	60
			1/8" sand	B	104	480	9.6	21.7	4.3	19.5	0.11		120	555	
			1" peat												

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
5A	4	36	6" floc	T	19	1060	1.3	1.8	0.6	33.2	0.11				
			30" muck	M	46	940	3.2	4.9	1.7	35.2	0.09		34	1885	18
				B	76	1230	4.5	6.2	2.0	32.4	0.12	111	27	555	63
													56	911	36
5B	5	40	5" floc	T	27	1500	1.3	1.8	0.5*	27.1					
			35" muck	M	67	900	4.3	7.4	1.7*	22.7					
				B	72	1090	4.6	6.6	1.8*	27.8					
5C	6	40	3" floc	T	18	1290	0.6	1.4	0.5	34.3					
			37" muck	M	48	1090	2.9	4.4	1.5	35.0	0.15	146	24	1722	21
				B	92	980	6.2	9.4	2.2	33.5	0.17	167	80	1833	19
5D	6	28	4" floc	T	31	1240	1.6	2.5	0.6*	24.9					
			24" muck(1)	M	74	860	4.8	8.6	1.9*	21.9					
				B	87	840	5.8	10.4	2.3*	21.8					
5E	6	36	3" floc	T	49	1070	2.9	4.6	1.1*	24.8					
			33" muck(1)	M	71	530	4.6	13.4	1.8*	13.5					
				B	95	800	6.4	11.8	2.5*	21.3					
5F	6	36	3" floc	T	42	1080	2.4	3.9	1.1	29.7	0.26	18			
			33" muck(1)	M	65	1050	4.1	6.2	1.8	28.7	0.34	36	32	522	56
				B	88	750	5.8	11.8	2.1	17.9	0.22	23	71	600	30
5G	5½	36	5" floc	T	34	1210	1.8	2.8	0.7*	25.9					
			31" muck(1)	M	107	1000	7.3	10.8	2.8*	26.6					
				B	111	930	7.6	12.0	3.0*	24.9					
5H	5½	40	6" floc	T	33	1220	1.8	2.7	0.8	12.4	0.28		39	1433	21
			34" muck(1)	M	60	950	3.8	6.3	1.7	27.5	0.26		50	788	34
				B	46	120	2.7	40.4	1.1	2.2	0.15		121	300	9
5I	5	24	3" floc	T	22	1570	0.9	1.4	0.4*	25.6					
			21" muck(1)	M	71	800	4.6	8.8	1.8*	20.6					
				B	72	600	4.6	12.2	1.8*	14.9					

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
5J	4½	28	5" floc	T	27	1420	1.3	1.9	0.5*	26.9					
			23" muck	M	85	1000	5.6	8.6	2.2*	25.6					
				B	139	1190	9.6	11.7	3.7*	32.6					
5K	5	24	3" floc	T	26	1180	1.5	2.2	0.7	31.0	0.13		29	1344	24
			13" muck	M	59	900	4.3	6.5	1.5	23.5	0.11	58	61	944	25
			8" peat	B	102	1730	5.7	5.9	2.4	39.7	0.09		17	289	141
6A	3½	30	1" floc	T	32	1330	1.6	2.4	0.8	34.2	0.12		35	1455	23
			29" muck	M	58	1290	3.1	4.5	1.4	31.1	0.37		28	622	50
				B	63	1290	3.3	4.9	1.6	32.2	0.18	70	32	655	50
6B	6½	30	2" floc	T	62	1290	1.5	4.8	1.7	32.0					
			28" muck	M											
				B	66	970	1.6	6.8	1.8	24.3					
6C	6	40	1" floc	T	114	1310	3.1	8.7	3.4	35.8					
			39" muck	M											
				B	77	1070	2.0	7.2	2.2	27.5					
6D	9½	22	2" floc	T	18	900	1.2	2.0	0.6	29.0	0.13		32	1555	19
			18" muck (1)	M	60	480	4.2	12.6	1.6	13.0	0.09		44	344	36
			2" shell	B	52	210	4.3	24.5	1.4	5.6	0.12		138	566	10
6E	6	40	3" floc	T	28	1400	1.3	2.0	0.5	26.3					
			37" muck	M	76	1060	5.0	7.2	2.0	27.0					
				B	77	1000	5.0	7.7	2.0	25.9					
6F	6	38	2" floc	T			2.6	4.0	1.0*	25.7					
			36" muck (1)	M			5.3	7.9	2.1*	26.4					
				B											
6G	6	36	1" floc	T	24	1500	1.1	1.6	0.4	28.0	0.20	12	25	1577	16
			31" muck	M	72	920	4.7	7.8	2.1	26.9	0.17	28	36	466	58
			4" shell	B	92	890	6.2	10.4	2.6	25.0	0.25	27	54	522	48

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
6H	6	30	1" floc	T	26	1440	1.2	1.8	0.5*	26.5					
			28" muck	M	50	1020	3.0	4.9	1.2*	24.3					
			1" sand	B	60	110	3.7	54.7	1.4*	2.6					
6I	5	40	1" floc	T	23	1640	1.0	1.4	0.4*	27.3					
			39" muck	M	69	1030	4.5	6.7	1.8*	26.1					
				B	79	880	5.2	9.0	2.0*	22.9					
6J	5½	35	3" floc	T	19	1000	1.3	1.9	0.6	30.5	0.06		32	1699	19
			32" muck	M	60	1040	3.8	5.8	1.8	31.2	0.02		57	977	32
				B	91	920	5.9	9.9	2.3	23.0	0.29		55	555	42
6K	6	38	2" floc	T	30	1300	1.5	2.3	0.6*	26.0					
			36" muck	M	61	1170	3.8	5.2	1.5*	29.1					
				B	63	1130	4.0	5.6	1.6*	28.3					
7B	6	32	2" floc	T	26	1530	1.2	1.7	0.6	33.4	0.03		30	1733	20
			30" muck	M	36	1440	1.8	2.5	0.9	35.6	0.09		52	2066	17
				B	44	1260	2.2	3.5	1.2	33.6	0.12		48	1377	25
7C	5	30	6" floc	T	25	1470	1.1	1.7	0.4*	27.0					
			24" muck	M	74	1030	4.8	7.2	1.9*	26.5					
				B	77	1100	5.0	7.0	2.0*	28.3					
7D	5	30	5" floc	T	29	1380	1.4	2.1	0.5*	26.4					
			25" muck	M	65	1100	4.2	5.9	1.6*	27.9					
				B	58	950	3.6	6.1	1.4*	23.2					
7E	11	24	3" floc	T	22	1830	0.9	1.2	0.5	36.6				1755	
			21" muck (1)	M	64	360	4.2	17.8	1.4	7.7				332	
				B	63	220	5.0	29.1	1.6	5.5				378	
7F	6½	29	5" floc	T											
			20" muck	M											
			4" clay	B	43	65	2.5	66.0	1.0*	1.4					

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
7G	6	29	10" floc	T	48	1140	2.8	4.2	1.1*	26.9					
			18" muck	M	51	1090	3.1	4.7	1.2*	26.1					
			1" sand	B	50	330	2.9	15.3	1.1*	7.7					
7H	7	21	½" floc	T	22	180	0.9	12.4	0.4	3.4	0.10	8	54	433	7
			20" muck (1)	M	35	70	1.9	50.9	0.4	0.8	0.28	23	68	133	6
			½" clay	B	56	100	3.4	55.7	0.5	0.8	0.62	40	56	100	9
7I	7	16	2" floc	T	30	1360	1.5	2.2	0.6*	26.8					
			9" muck	M	62	460	3.9	13.6	1.5*	11.3					
			5" shell	B	57	140	3.4	39.8	1.3*	3.4					
7J	4	31	3" floc	T	30	1360	1.5	2.2	0.6*	27.6					
			28" muck	M	59	1180	3.7	5.0	1.4*	29.0					
				B	65	1080	4.1	6.0	1.6*	27.2					
8C	6	40	1" floc	T	30	560	1.5	5.4	0.6	11.2	0.30	13	47	877	13
			39" muck (1)	M	68	1050	4.4	6.5	2.0	30.1	0.14	69	30	455	67
				B	73	1010	4.7	7.2	2.1	29.1	0.20	87	34	477	62
8D	5	40	2" floc	T	27	1500	1.3	1.8	0.5*	27.9					
			38" muck	M	43	1130	2.5	3.8	1.0*	26.2					
				B	59	1020	3.7	5.8	1.4*	25.0					
8E	7	40	2" floc	T	32	1330	1.6	2.4	0.6*	26.8					
			38" muck	M	75	1080	4.9	7.0	1.9*	27.5					
				B	86	840	5.7	10.3	2.2*	21.7					
8F	5	40	1" floc	T	88	5500	1.0	1.6	0.5	31.8	0.32		22	1400	23
			39" muck	M	131	1930	4.2	6.8	1.8	26.8	0.08		36	533	50
				B	137	1730	4.8	7.9	2.1	26.0	0.13		33	410	64
8G	5½	30	1" floc	T	27	1420	1.3	1.9	0.5*	26.2					
			28½" muck	M	83	760	5.5	10.9	2.1*	17.7					
			½" shell	B	96	630	6.5	15.2	2.5*	16.7					

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
8H	5½	30	2" floc	T	14	3500	0.3	0.4	0.1*	28.7					
			26" muck	M	67	1100	4.2	6.1	1.7*	27.8					
			2" sand	B	25	30	0.7	74.1	0.3*	0.6					
8I	6	10	1" floc	T	7	1400	0.3	0.5	0.2	37.4	0.12	15	10	1732	20
			7" muck	M	44	220	2.6	20.0	1.3	6.3	0.14	25	68	344	19
			2" sand	B	25	40	1.5	70.6	0.8	1.0	0.20	12	40	56	20
9D	10	26	1" floc	T	94	4100	1.4	2.0	0.7	32.6	0.24	51	34	1666	21
			24" muck	M	115	2350	3.2	4.9	1.4	27.5	0.27	84	49	1000	29
			1" shell	B	41	70	2.3	57.5	0.6	0.9	0.20	16	268	466	2
9E	5	40	3" floc	T	30	1360	1.5	2.2	0.6*	26.7					
			37" muck (1)	M	69	1150	4.5	6.0	1.8*	29.1					
				B	79	1160	5.1	6.8	2.0*	29.6					
9F	5	40	2" floc	T	28	1330	1.4	2.1	0.6*	26.7					
			38" muck (1)	M	77	1120	5.0	6.9	2.0*	28.8					
				B	83	1120	5.4	7.4	2.1*	29.2					
9G	5	40	2" floc	T	20	1110	1.8	1.8	0.6	32.4	0.19	22	29	1610	21
			38" muck	M	86	1210	5.0	7.1	1.9	27.0	0.14	38	25	355	76
				B	92	1240	5.4	7.4	2.3	30.0	0.21	21	25	333	92
9H	4½	40	4" floc	T	35	1250	1.9	2.8	0.8*	26.5					
			36" muck	M	83	940	5.4	8.8	2.1*	24.5					
				B	89	1000	5.9	8.9	2.3*	26.3					
9I	4	40	2" floc	T	30	1360	1.5	2.2	0.6*	26.3					
			38" muck	M	59	1020	3.7	5.8	1.5*	25.1					
				B	71	990	4.6	7.2	1.8*	25.2					
10D	5½	40	2" floc	T	18	2000	0.6	0.9	0.2*	27.0					
			38" muck	M	63	1130	4.0	5.6	1.6*	28.2					
				B	67	3940	4.2	6.0	1.7*	28.0					

STA-TION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
10E	5	40	2" floc	T	26	1530	1.2	1.7	0.6	33.2	0.41	12	29	1677	21
			38" muck (1)	M	66	970	4.2	6.8	1.9	27.0	0.46	48	38	555	50
				B	80	1550	5.2	7.6	2.0	25.8	0.26	42	35	333	57
10F	4½	40	3" floc	T	21	1050	1.3	2.0	0.7	33.1	0.17	40	35	1777	20
			37" muck	M	78	1180	4.8	6.6	1.9	28.0	0.18		28	422	68
				B	85	1250	4.8	6.8	2.0	28.6	0.20	32	23	333	87
10G	4½	40	5" floc	T	33	1270	1.7	2.6	0.8*	26.4					
			35" muck	M	82	1340	5.4	7.9	2.1*	27.1					
				B	82	1090	5.4	7.5	2.1*	28.3					
10H	3	40	4" floc	T	27	1350	1.3	2.0	0.6	28.6	0.30	39	16	788	38
			36" muck	M	127	190	3.9	5.8	1.8	30.7	0.20	98	32	555	56
				B	134	1720	4.6	7.8	2.0	25.4	0.44	95	44	566	45
Citrus 2 S.T.P.	1	40	2" floc	T	36	250	2.4	14.5	1.0	7.0	0.24	128	583	4010	2
			38" muck	M	117	2090	3.5	5.6	1.7	30.6	0.31	119	51	910	33
				B	134	2000	4.7	6.7	2.2	32.4	0.28	107	34	500	65
11C	5	40	2" floc	T											
			6" muck (1) (2)	M	75	1060	4.8	7.1	1.9*	26.0					
			32" muck	B											
11D	4	40	8" floc	T	27	960	1.8	2.8	0.9	31.9	0.18	48	40	1455	23
			32" muck	M	65	990	3.8	6.6	1.7	25.2	0.05	39	26	389	65
				B	79	1180	4.7	6.7	2.0	30.1	0.18	39	27	400	74
11E	4	40	6" floc	T	28	1120	1.6	2.5	0.5	19.7	0.26	44	39	1566	13
			34" muck	M	78	1160	4.5	6.7	2.1	31.3	0.10	45	27	400	78
				B	82	1050	4.7	7.8	2.0	26.1	0.09	49	43	555	47
11F	4	40	2" floc	T	28	1400	1.3	2.0	0.5*	26.7					
			38" muck	M	67	1060	4.2	6.3	1.7*	26.5					
				B			5.1	7.0	2.0*	28.5					

STA-TION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
11a	4½	40	6" floc	T	21	1240	1.3	1.7	0.6	34.4	0.18	31	23	1355	26
			34" muck	M	47	1180	2.8	4.0	1.1	27.3	0.10	46	12	300	92
				B	52	1160	3.2	4.5	1.4	31.8	0.06	68	19	422	74
11c	4½	40	8" floc	T	19	1000	1.3	1.9	0.6	32.9	0.15		30	1588	20
			32" muck	M	61	1220	3.5	5.0	1.5	30.6	0.09		27	533	56
				B	74	1200	4.2	6.2	1.7	26.9	0.02		30	478	57
12a	2	9	1" floc	T	26	1130	2.0	2.3	0.7	32.0		22	13	566	54
			8" muck (2)	M	127	1260	8.4	10.1	3.1	30.9	0.28	21	42	422	74
				B	117	1100	8.8	10.6	3.7	35.0	0.32	15	43	410	86
12B	5	40	12" floc	T	21	1170	1.3	1.8	0.6	33.5	0.18	33	24	1332	25
			28" muck	M	55	1170	3.4	4.7	1.5	31.2	0.10	47	25	533	60
				B	64	1210	3.8	5.3	1.6	29.4	0.17	48	31	577	52
12b	5	40	6" floc	T	33	1380	1.7	2.4	0.7*	28.0					
			34" muck	M	69	1000	4.4	6.9	1.7*	25.3					
				B	74	1060	4.8	7.0	1.9*	27.0					
12C	4	40	7" floc	T	24	1500	1.1	1.6	0.4*	34.5				1555	22
			33" muck	M	63	990	4.0	6.4	1.6*	28.5				389	29
				B	85	1060	5.6	8.0	2.2*	27.5				433	50
12c	4	40	7" floc	T	24	1500	1.1	1.6	0.4*	26.6					
			33" muck	M	63	980	4.0	6.4	1.6*	24.3					
				B	85	1060	5.6	8.0	2.2*	27.8					

STATION	WATER DEPTH (feet)	CORE LENGTH (inches)	CORE CHARACTER (top to bottom)	SAMPLE[3]	COD (mg/g) wet basis	COD (mg/g) dry basis	VOLATILE SOLIDS (%)	TOTAL SOLIDS (%)	TKN[4] (mg/g) wet basis	TKN[4] (mg/g) dry basis	NO_3+NO_2-N (mg/kg)	NH_3-N (mg/kg)	PO_4-P (mg/kg) wet basis	PO_4-P (mg/kg) dry basis	N-P RATIO
13b	1½	40	12" floc	T	19	1360	1.0	1.4	0.4	31.8	0.08	30	18	1266	24
			28" muck	M	37	1190	2.2	3.1	1.1	35.0	0.19	99	42	1355	28
				B	67	1120	3.8	6.0	1.6	27.0	0.19	74	32	544	123
13C	7	40	6" floc	T	21	540	2.6	3.9	1.2	30.8	0.27	60	50	1266	
			34" muck	M	51	1110	3.1	4.6	1.4	24.0	0.15	100	50	1088	
				B	77	1220	4.3	6.3	1.6	25.1	0.16	8	13	1210	

(1) Mixture of muck and shell.
(2) Vegetative Detritus.
(3) Analytical results were for top (T), middle (M), and bottom (B) of the core only. No analyses were performed on the floc layer.
(4) TKN - Total Kjeldahl Nitrogen.
* Calculated value.

APPENDIX C

ANALYSIS DATA FOR SHALLOW WELLS, ARTESIAN WELLS, THE FLOWING SPRING AND RAINWATER

SHALLOW WELLS

NUMBER	LOCATION	SIZE	DEPTH	TKN mg/1	NO_3-NO_2 mg/1	NH_3 mg/1	P mg/1
1.	Cross Orange Groves Oakland, Fla.	1½"	5 ft.	1.80	2.74	0.20	2.80
2.	Killarney Trailer Ct. Jones Rd. Killarney, Fla.	1½"	7 ft.	4.40	25.00	0.49	52.90
3.	Osgood Orange Groves Monteverde, Fla.	1½"	4 ft.	2.80	30.60	0.25	1.40

ARTESIAN WELLS

1.	Killarney Trailer Ct. Jones Rd. Killarney, Fla.	2"	95 ft.	< 0.10	< 0.01	0.03	0.03
2.	Winter Orange Grove Sunshine Pky. Access Rd. Lake Co., Fla.	4"	173 ft.	0.16	< 0.01	0.06	0.06
3.	Lykes Orange Grove Pine Island Lake Co., Fla.	-	-	< 0.10	< 0.01	0.02	0.02
4.	Monteverde Academy Highway 455 Monteverde, Fla.	-	-	0.10	< 0.01	0.09	0.85
5.	Cross Orange Groves Oakland, Fla.	2"	150 ft.	0.10	0.03	0.03	0.01
6.	Hooper Farms Near Plymouth, Fla.	-	-	0.52	< 0.01	0.32	0.03

FLOWING SPRING

1.	Gourd Neck Spring (Apopka Springs)	Sample taken at 25 ft. depth		0.74	0.66	0.07	0.07

RAIN SAMPLES

1.	0.4" Rain 3/6/68 Winter Garden Motel			0.58	0.06	< 0.01	0.08
2.	0.8" Rain 8/10/68 Fisherman's Paradise			0.32	0.10	0.14	0.01
3.	0.4" Rain 3/12/68 Winter Garden Motel			0.30	0.78	0.09	0.09

APPENDIX D

CORRESPONDENCE

STATE OF FLORIDA
Office of the Governor
TALLAHASSEE

C-O-P-Y

Claude R. Kirk, Jr.
Governor

November 22, 1967

Mr. John R. Thoman
U. S. Department of the Interior
Federal Water Pollution Control
Administration
Suite 300
1421 Peachtree Street, Northeast
Atlanta, Georgia 30309

Dear Mr. Thoman:

Restoration of the eutrophied Lake Apopka is one of the prime projects of this administration. It was concluded by the members of the Lake Apopka Technical Committee that a biological-chemical survey of Lake Apopka and its tributary lakes is needed to ascertain the extent of the problems associated with this portion of the Oklawaha River Basin.

It would be appreciated if you would initiate proceedings for enacting such a survey with the chairman of the Lake Apopka Technical Committee.

Your cooperation on this matter will be of the utmost importance towards restoration of this river basin.

Sincerely,

Governor

CRK/rmb

C-O-P-Y

November 28, 1967

Honorable Claude R. Kirk, Jr.
Governor
State of Florida
Tallahassee, Florida

Dear Governor Kirk:

Many thanks for your letter of November 22, 1967 concerning Lake Apopka. I assure you that we will do everything within the limits of our resources to assist in the restoration of Lake Apopka.

At the present time we are evaluating all of the data collected during the last several years by the many groups which have studied the lake. We believe that sufficient information is now available to describe the problem except for one deficiency in the biological area. As soon as this review is finished -- hopefully by the end of the year -- we will be able to recommend to the chairman of your technical committee what, if any, additional work is required.

Perhaps the greatest challenge lies in the interpretation of the data as related to proposed structures. Too often in the past physical rearrangement has been tried with little concern for the effects on the long-term ecology of the area. We hope that we will be able to comment meaningfully on this point.

Again, I assure you that we will do everything we can to assist.

Sincerely,

John R. Thoman
Regional Director

cc: Mr. C. W. Sheffield
Traina (Attachment)

C-O-P-Y

January 9, 1968

Honorable Claude R. Kirk, Jr.
Governor of Florida
Tallahassee, Florida

Dear Governor Kirk:

In my letter to you of November 28, 1967, I promised to let you know later of our findings concerning Lake Apopka. Our staff at the Southeast Water Laboratory has completed its analysis and the major findings are shown in the attached memoranda.

The problem of Lake Apopka is two-fold. Nutrients from man-made sources must be stopped being added to the lake. The second problem is the restoration of the lake itself by reversing the eutrophication process. The first is relatively easy to solve--the second is extremely difficult to solve.

As a step in the right direction, I recommend that efforts be initiated immediately to stop the discharge of nitrogen and phosphorus to Lake Apopka by the Zellwood Farms, the Winter Garden Citrus Co-op, and the City of Winter Garden. Feasible treatment devices and methods are available, and competent consulting engineers can advise the entities as to their application. Whether or not these procedures are economically feasible I am not prepared to answer. Their application in relation to the socio-economic factors involved has not been evaluated. Their use would be in order regardless of the ultimate decision as to whether or not Lake Apopka can be restored since some body of water must always receive these discharges.

Secondly, three studies are needed to round out the data to permit a preliminary assessment of the possibilities of restoring the lake. We will begin these three studies within the next month, and Mr. Traina of our staff will contact Mr. Sheffield to arrange the details.

In addition, we will need chemical data now being collected by the Florida Game and Freshwater Fish Commission at its Eustis Laboratory. We were refused this information recently when we requested it from the laboratory. We will also need as much information as is available concerning pumping from the Zellwood Farms. The Florida State Board of Health attempted to get this information during its two-year study of the lake which was completed in 1964. The report states that the data were promised but later refused. Perhaps through your good offices this information can be made available to us.

After we have conducted the three studies and received the additional information requested, we should be in a better position to make meaningful comments concerning a future course of action for efforts to restore Lake Apopka. Frankly, some of our scientists and engineers think it is an impossible task. I, for one, do not think so, and hope that it will be possible to develop a meaningful course of action that will restore the lake for a wide variety of beneficial uses.

Sincerely yours,

John R. Thoman
Regional Director

cc: Mr. C. W. Sheffield
Mr. David B. Lee

United States Government
MEMORANDUM

C-O-P-Y

TO : Paul J. Traina, Director
Technical Programs

DATE: December 29, 1967

FROM : Robert F. Schneider

SUBJECT: Lake Apopka, Florida

Problem:

Lake Apopka is eutrophic, and man is accelerating the terminal stages through addition of nutrients such as nitrogen (N) and phosphorus (P).

Associated Effects:

1. Perpetual algal bloom.
2. Unconsolidated bottom deposits
3. Poor fishery.
4. Reduced recreational use.
5. Irate land owners.

Alleged Causes of Over-nutrification:

1. Muck farm waste water

   A. Total nitrogen ranges from 1600 to 16,000 lbs/day.
   Total phosphorus ranges from 65 to 650 lbs/day.
   (Reference: Florida State Board of Health Report of 1965)

2. Untreated citrus processing waste from the Coop plant in Winter Garden.

   A. Total nitrogen estimated at 192 lbs/day.
   Total phosphorus estimated at 9.6 lbs/day.
   (Reference: Florida State Board of Health Report of 1965)

3. Sewage from City of Winter Garden

   A. Prior to 1948, a total of 123,281.8 lbs of nitrogen and 61,000 lbs of phosphates were discharged to Lake Apopka from The Winter Garden's Imhoff tank.
   (Reference: Florida State Board of Health Summary Report of February 18, 1964)

   B. Nutrients discharged from the existing secondary treatment facility are estimated as: total nitrogen of 75 lbs/day, and total phosphorus of 19 lbs/day.
   (Reference: Florida State Board of Health Report of 1965)

4. Phosphorus from Gourd's Neck spring (principal continuous freshwater source)

   A. Insufficient data.

5. Natural drainage and leaching of nitrogenous fertilizers from orange groves.

   A. Insufficient data.

6. Hyacinths sprayed and left to decompose in past years.

   A. No quantitative data available.

7. Trash fish "poisoned" and left to decompose.

   A. Twenty million pounds of shad left to decompose in Lake Apopka (1957-1959) released 226,200 lbs of nitrogen and 306,240 lbs of phosphorus.
   (Reference: Memorandum from W. M. Beck, Jr., to D. B. Lee on May 9, 1967)

8. Fixing of nitrogen by bluegreen algae dying, decaying and releasing "bound fertilizers."

   A. The Lake is pea soup color, and below two feet there is insufficient light for photosynthesis; hence, the shaded plantlife dies. No estimate of nutrient input by nitrogen fixation.
   (Reference: J. B. Lackey's report #V)

9. Lowering Lake level.

   A. Reduced water volume adversely affected assimilative capacity of the Lake and increased the importance of nutrient recycling from bottom sediments.
   (Reference: M. T. Huish, Personal Communication)

Proposed Solutions (from various interested agencies):

The reclamation of Lake Apopka and/or protection of chain-of-lakes via any of the following suggested methods must be preceded by nutrient removal treatment in all industrial, domestic and significant agricultural waste sources in the area. The feasibility of these reclamation methods is not evaluated here.

1. Dredging

   A. Selectively dredge richest deposits.

   B. Sacrifice a portion of the Lake for spoil disposal, dewatering and conversion into additional muck farmland, or

   C. Dispose of spoil in citrus areas needing additional nutrients.

   D. Establish and maintain desirable marginal vegetation, under some control, to prevent lake coverage.

2. Lake Drawdown

   A. Lower lake level in order to expose a portion of the lake bottom.

   B. Dewater exposed shoreline bottom sediment.

   C. Remove nutrient-rich sediment with dragline or bulldozing equipment.

   D. Dispose of enriched spoil on nearby farmland.

   E. Refill lake and inundate cleared shoreline.

3. Drain Lake

   A. Construct a temporary levee at the mouth of Gourd Neck.

   B. Circumvent the Lake via a canal connecting the spring with the existing Beauclair Canal.

   C. Chemically treat the Lake to reduce algae bloom or reduce algae content by other means.

   D. Slowly lower the lake level allowing a pre-determined quantity of lake water to mix with spring water and discharge to the downstream chain of lakes.

   E. Dike the Lake and channel drainage to Beauclair Canal.

   F. Convert the lake bottom into additional muck farmland.

4. Harvest Algae

   A. This would require a lengthy research program to determine an adequate method. Flotation, screening, chemical precipitation and removal and centrifugation have all been mentioned as methods of algae removal.

1. Dredging

   A. Selectively dredge richest deposits.

   B. Sacrifice a portion of the Lake for spoil disposal, dewatering and conversion into additional muck farmland, or

   C. Dispose of spoil in citrus areas needing additional nutrients.

   D. Establish and maintain desirable marginal vegetation, under some control, to prevent lake coverage.

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   A. Lower lake level in order to expose a portion of the lake bottom.

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   A. Construct a temporary levee at the mouth of Gourd Neck.

   B. Circumvent the Lake via a canal connecting the spring with the existing Beauclair Canal.

   C. Chemically treat the Lake to reduce algae bloom or reduce algae content by other means.

   D. Slowly lower the lake level allowing a pre-determined quantity of lake water to mix with spring water and discharge to the downstream chain of lakes.

   E. Dike the Lake and channel drainage to Beauclair Canal.

   F. Convert the lake bottom into additional muck farmland.

4. Harvest Algae

   A. This would require a lengthy research program to determine an adequate method. Flotation, screening, chemical precipitation and removal and centrifugation have all been mentioned as methods of algae removal.

5. Increase Lake Level - as means of reducing importance of recycled bottom nutrients.

   A. Raise height of existing dike or construct a new higher dike.

   B. Remove terrestrial plants that would be inundated.

   C. Increase the Lake's depth by filling it to the higher elevation.

6. Stabilize Bottom Sediments

   A. Locate richest deposits.

   B. Add inert material to seal, or

   C. Add such compounds as $FeSO_4$ to fix nutrients, e.g. phosphates.

Studies Needed

1. Map the location, depth and extent of unconsolidated muck on the lake bottom.

   A. Special Equipment

      1) Portable recording fathometer
      2) Core sampling device
      3) Magnetic compass for course lines
      4) Velocity meter

   B. Personnel

      1) Sampling team of two men

   C. Time

      1) Field sampling period of 2 weeks.

2. Chemical evaluation of selected core samples to show nutrient quantity and quality of layered material.

   A. Special Equipment

      1) Core sampling device
      2) Facilities for freezing and shipping cores to laboratory

   B. Personnel

      1) Sampling team of two men
      2) Chemist and technician

C. Time

1) Field sampling period of one month
2) Laboratory analyses period of three months

3. Chemical evaluation of nutrients from Gourd's Neck Springs, orange grove drainage, and rainfall.

A. Special Equipment

1) Rain gauge
2) Water sampling equipment
3) Velocity meter for measuring spring outflow

B. Personnel

1) Sampling team of two men
2) Chemist

C. Time

1) Field sampling period:

a) Gourd Neck Spring once per week for duration of study.
b) Orange grove drainage station sampled following each rainfall during the study.

2) Laboratory analyses period of two weeks.

Historical Summary (Since 1946)

By 1946 the eutrophic condition of Lake Apopka had advanced to the stage of littoral vegetation having gained foothold throughout most of the lake bottom. The following year, large quantities of aquatic plants were uprooted by a hurricane. This was followed by the first reported bloom of algae in the fall of 1947. The dense attached vegetation (Vallisneria) never became established in the Lake again, probably because of a partial black-out effect caused by the algal bloom. The character of the Lake was materially changed.

In 1948 the Beauclair Canal was opened, and in 1952 a control structure was installed. From that point on, the Lake became a mismanaged reservoir. Lake drawdown for fish management was ignored. During the rainy season, the surrounding muck farms pumped excess water from their fertilized fields into the Lake. Untreated citrus processing wastewater continued to be poured into the Lake. Unknown acreages of hyacinths were sprayed and left to decompose. The abuses continued, and they are so lengthy a list that it becomes a task to enumerate them. As the nutrients increased, so did the quantity of algae. Blooms became persistent,

and the Lake resembled pea soup aesthetically. Irate fishermen began to seek other fishing areas.

The Florida Game and Freshwater Fish Commission investigated in 1956. Their survey revealed that game (sport) fish were gone, by migration, death, or failure to spawn. The Commission reported a species composition by weight of 82 percent rough fish (mostly shad) and 18 percent game fish.

The Lake was treated for Gizzard Shad and Threadfin Shad removal for three successive years. It was estimated by M. T. Huish, Project Leader for the Commission, that 20 million pounds of shad were killed during the three operations. These fish were left to decompose in the Lake. As a result of released nutrients bound in the bodies of the shad, an extremely dense phytoplankton bloom followed each treatment.

The accumulative effects of phytoplankton blooms since 1947 have had a drastic effect on the biological conditions in Lake Apopka. The dense blooms shade underlying phytoplankton causing them to die and sink to the Lake bottom forming unconsolidated deposits of organic material. These flocculent deposits are anaerobic and do not afford a suitable habitat for benthic biota. Hence, forage fish seeking food and spawning grounds are restricted to the small remaining productive zone around the Lake perimeter. The Florida State Board of Health estimates the productive area to be less than 2,000 acres in this 30,000-acre lake.

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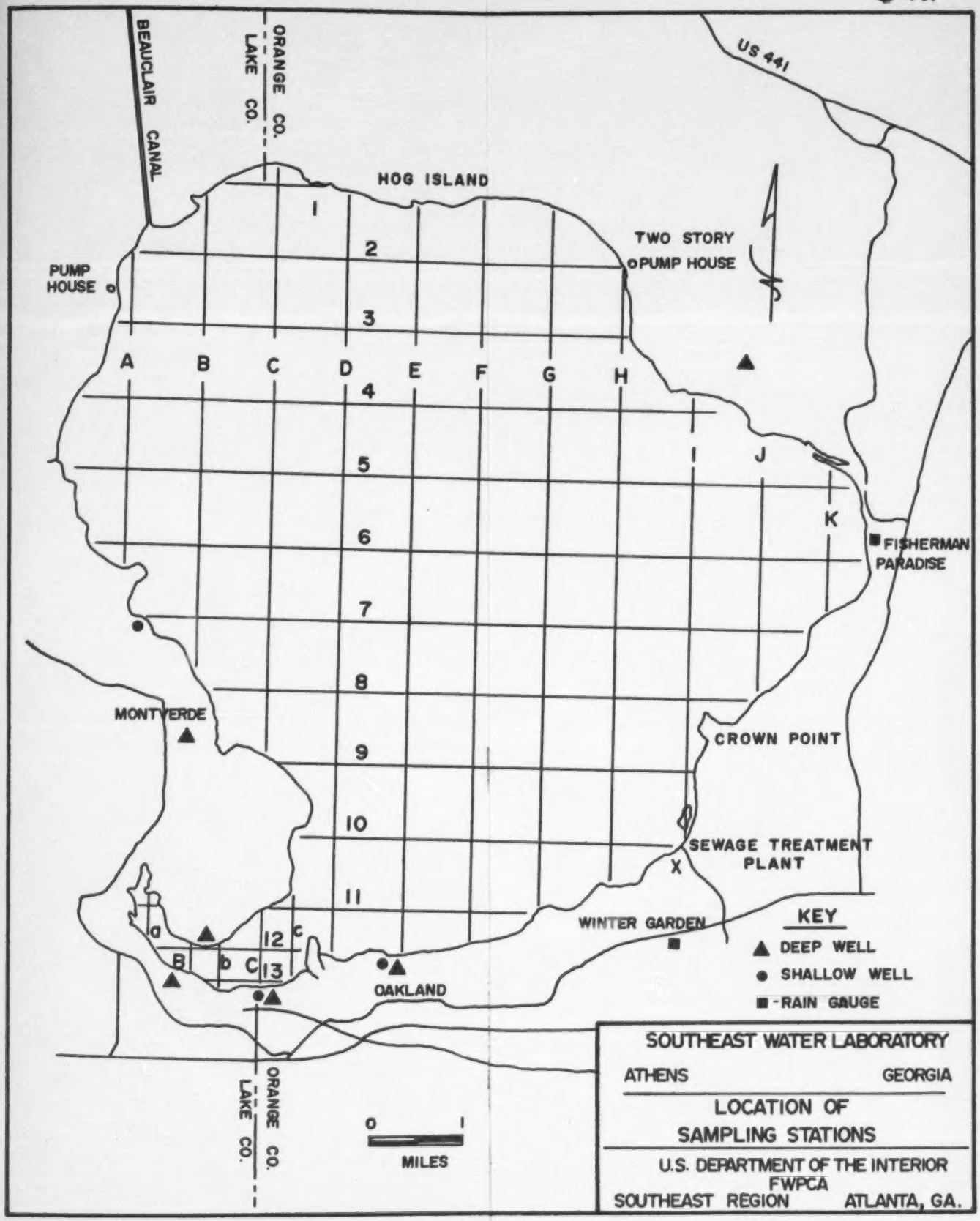
BEAUCLAIR CANAL
ORANGE CO.
LAKE CO.
US 441
HOG ISLAND
PUMP HOUSE
TWO STORY PUMP HOUSE
A
B
C
D
E
F
G
H
I
J
K
1
2
3
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6
7
8
9
10
11
12
13
a
b
c
FISHERMAN PARADISE
MONTVERDE
CROWN POINT
SEWAGE TREATMENT PLANT
X
WINTER GARDEN
OAKLAND
KEY
DEEP WELL
SHALLOW WELL
RAIN GAUGE
0
1
MILES
SOUTHEAST WATER LABORATORY
ATHENS GEORGIA
LOCATION OF SAMPLING STATIONS
U.S. DEPARTMENT OF THE INTERIOR
FWPCA
SOUTHEAST REGION ATLANTA, GA.

Figure 2.